

**Sacramento River Flood Control System Evaluation  
Initial Appraisal Report - Lower Sacramento Area**

**Attachment B**

**Basis of Design  
Geotechnical Evaluation of Levees  
February 1993**

**October 1993**

BASIS OF DESIGN  
GEOTECHNICAL EVALUATION OF LEVEES  
FOR  
SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO RIVER AREA, PHASE IV

February 1993

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BASIS OF DESIGN  
GEOTECHNICAL EVALUATION OF LEVEES  
FOR  
LOWER SACRAMENTO RIVER AREA, PHASE IV

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## APPENDIX A - RECONSTRUCTION ALTERNATIVES

<u>ALTERNATIVE</u>	<u>DESCRIPTION</u>	
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D	Slurry Cutoff Wall (30 to 40 feet deep)	A4
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## APPENDIX B - SELECTED PHOTOGRAPHS

BASIS OF DESIGN  
GEOTECHNICAL EVALUATION OF LEVEES  
FOR  
SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO RIVER AREA, PHASE IV

A. INTRODUCTION.

This study was performed to evaluate the flood control levees in the Lower Sacramento River Area. The study evaluates past problems and determines which areas require reconstruction or repair. Most of the Lower Sacramento River Area, Phase IV, of the Sacramento River Flood Control System is located in the Sacramento-San Joaquin Delta area. The study area includes approximately 221 miles of flood control levees. The levees in the study area are shown on the Location Map, Figure 1 and in greater detail on the Area Maps, Figures 2 thru 5. About 75 miles or one-third of the levees in the study area are located along the Sacramento River. The remaining levees line nine sloughs tributary to the Sacramento River. These sloughs include; Cache, Georgiana, Steamboat, Elk, Sutter, Lindsey, Miner, Threemile, and Haas.

The levee and foundation soils are extremely variable. The foundation in portions of the study area along the Sacramento River consist of relatively firm silt and clay soils. In other areas, mostly in the southern portion of the study area, the foundation is less desirable, consisting of loose sand deposits, organic clay or weak peat deposits remaining from the original tule beds of the Delta. These soils, although ideal for farming, generally have undesirable structural characteristics including low shear strength and low density which have led to levee instability problems in some areas. In some areas, clean sand levee and foundation soils have contributed to nuisance and sometimes dangerous seepage conditions.

The study was accomplished in three phases. Phase one was completed by the Architect Engineering (A/E) firm Harlan Tait Associates in April 1990 (Ref. 1). The phase one study included an inventory of reported problem areas by the California Department of Water Resources (DWR), a preliminary assessment of all 221 miles of levees in the study area, and developing an exploration program for the phase two study. The phase two study, also performed by Harlan Tait Associates, was a comprehensive evaluation of the condition of approximately the southerly one half (90 miles) of the study area. That study included explorations, analyses, and recommendations for levee improvements (Ref. 2).

This report is considered to be the third and final phase and was completed "in-house" by the Sacramento District, Geotechnical Branch, Soil Design Section. As well as evaluating the remaining 131 miles of levees in the northern portion of the study area, the "in-house" study reexamined the recommendations made in the phase two study and makes final recommendations for reconstruction of various levee reaches in the entire Phase IV Study Area.

B. EXPLORATIONS.

Explorations used in this study include pre-1986 borings, borings performed during the phase two study (1990) and borings performed during the phase three study (1991). Between May and June 1990, as part of the phase two study, a total of 35 borings were drilled (2F-90-1 through 2F-90-25). Twenty-two of these were drilled from the levee crown and 13 were

drilled at the levee landside toe. These borings were performed with a 5-inch diameter auger and included Standard Penetration Tests (SPT). Between June and August 1991, as part of the phase three study, the Corps of Engineers drilled another 81 borings (2F-91-1 through 2F-91-44). These borings were drilled with a 6-inch diameter auger and also included SPTs. Both the 1990 and 1991 exploration program included undisturbed sampling of selected fine grained soil deposits as well as baggy samples collected for soil classification testing. Borings drilled at the landside toe of the levee are designated with an "A" after the boring number. The phase two and phase three borings were generally drilled in locations where past levee problems have been reported.

#### C. LABORATORY TESTING.

Laboratory testing prior to the 1990 exploration program is generally limited. All laboratory testing for the phase two (Ref. 3) and phase three (Ref.4) studies were performed by the South Pacific Division Laboratory, located in Sausalito, California. Testing included soil classification, triaxial shear and unconfined shear strength tests, and consolidation tests. Shear strength test results were used to determine strength properties of soils for stability analyses. Fines content (minus 200 sieve size) of samples tested are shown in percent minus 200 sieve size on individual soil logs shown on the levee profiles Plates 6 through 35.

#### D. BASIS FOR EVALUATIONS.

A total of 25 sites were identified for reconstruction or repair and are shown on Table 1. In general, recommendations are not made for sites where bank sloughing or erosion is the reported problem. Routine bank erosion should be repaired by local reclamation districts. High water marks were recorded during the February 1986 flood and are shown in profile on Figures 6 through 35 along with the design flood plane elevation. The 1986 high water marks were generally within 1 foot above or below the design water surface. Flood fighting techniques including sandbagging around sand boils were used in several locations in 1986. These efforts may have prevented several levee failures. However, it cannot be assumed that future flood fight efforts will always occur timely enough to prevent failure. In addition, in spite of the seemingly large number of explorations conducted, there are many unknown soil conditions in the system. The levee and foundation conditions are extremely complex. Additionally, natural erosion of the levees and riverside berms occur continually. Several examples of this are included in this report and are shown in the photographs in Appendix B. Flood duration affects the degree of levee saturation, and consequently has an overall affect on levee stability. Levee failures can and have occurred at times other than at peak levels. An example of this is the February 20, 1986 Linda levee failure on the left bank of the Yuba River where the levee breached after the river was receding from the peak flood level. Therefore, the conclusions in this report are not based entirely on whether or not a particular site had serious problems while passing the recent flood events. The conclusions are based on past performance as determined from Corps files and reports of performance by local representatives, field observations, levee and foundation soil conditions as determined from the explorations, analyses, and geotechnical engineering judgement.

In some locations, seepage conditions are believed to be more of a nuisance than a real threat to levee stability. In some instances, seepage is generalized and occurs a hundred or more feet from the levee toe. In many cases, this type of seepage results from relatively deep sand deposits where the groundwater level increases during high river stage. In other areas, the seepage is considered potentially threatening to the levee stability and this report makes

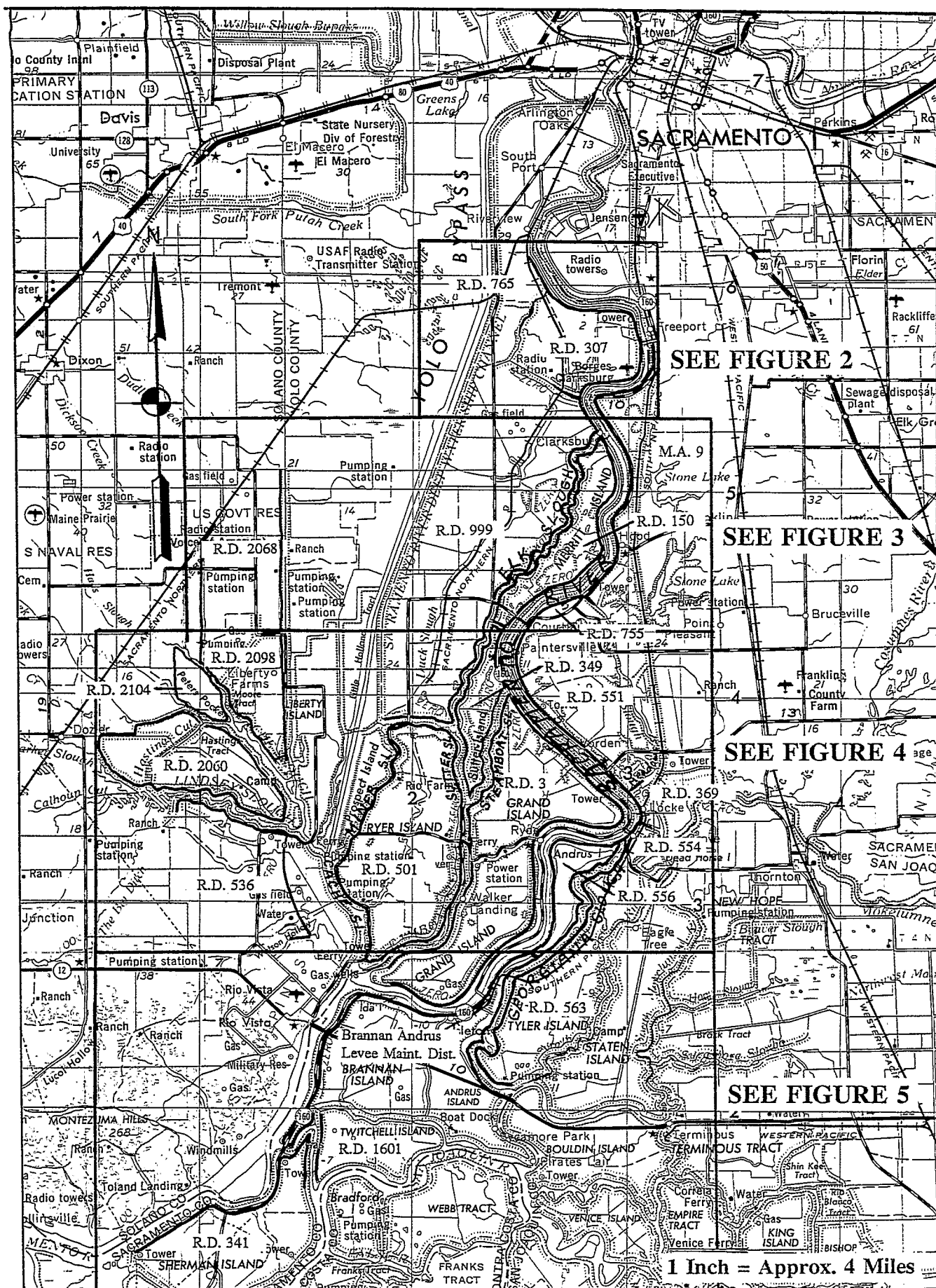


FIGURE 1

**C - 1 0 3 5 3 1**

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recommendations to control the seepage.

The recommendations in this report are based on current bank conditions. Continual waterside bank erosion can decrease overall levee stability. This is particularly true where levees overlies relatively pervious deposits. As the waterside foundation erodes, the seepage path decreases and water forces increase under the levee and near the landside toe. The effect is a decrease in slope stability as well as an increase in the potential for foundation piping. In this report, where it is believed that bank erosion is becoming critical, recommendations are made for slope protection. But in general, most of the erosion is not critical and should be accomplished by the local reclamation district as part of routine maintenance. Performing all of the reconstruction or repairs recommended in this report does not insure that future levee problems will not occur. The variability of the soil conditions and the dynamic nature of the levees and the foundations make it virtually impossible to identify and prevent all future problems. In addition, ongoing maintenance will continue to be necessary. Surveillance, particularly during floods, will continue to be essential in maintaining the integrity of the levee system.

Of the 221 miles of levee in the study area, approximately 17 miles (25 sites) are identified as in need of reconstruction or repair. A summary of the recommended reconstruction sites are identified in Table 1. Sites in need of operation and maintenance repairs as well as bank protection are listed in Table 2. The site numbering system was adopted with some additions from the original site numbers identified in the phase one study. The first part of the number is the reclamation district, ie. 563-1 would be site 1 in R.D. 563. Schematics of some of the recommended alternatives are included in Appendix A. Selected photographs are included in Appendix B. The remainder of the report, beginning with paragraph E, describes and evaluates the study area by geographical locations typically by sloughs or river reaches. Figures 6 through 35 are profiles of the various reaches. The profiles include reported problem areas, phase two recommendations, and the final Corps of Engineers recommendations for each reach.

**TABLE 1**  
SITES RECOMMENDED FOR RECONSTRUCTION

SITE NUMBER	PROBLEMS/CONCERNS	RECONSTRUCTION ALTERNATIVES	SITE LENGTH	PHOTO NUMBER
MA9-2A to 4E	Seepage and Numerous Sand Boils	Seepage/Stability Berm, Alternative A or B	2.2 miles	-
MA9-4A	Seepage and Numerous Sand Boils	Seepage/Stability Berm, Alternative A or B	2000 feet	-
MA9-5	Seepage and Numerous Sand Boils	Seepage/Stability Berm, Alternative A or B	7200 feet	-
1601-1	Seepage and Landside Slope Stability	Seepage/Stability Berm, Alternative C	10,600 feet	-
563-1	Seepage	Seepage Berm, Alternative C	1000 feet	4
563-2	Sloughing of Landside Slope and Seepage at landside toe	Reconstruct landside slope from its present 1V on 1.5H to 2H to 1V on 3H	1000 feet	5 & 6
563-4	Seepage in Irrigation Ditch	Relocate Irrigation Ditch at least 75 feet from levee landside toe.	4500 feet (Note 1)	7
556-2	Seepage and Sand Boils	Backfill Irrigation Ditch and Construct Seepage Berm Alternative F	4800 feet	8
BA-1	Chronic Foundation and Through Levee Seepage	Stability Berm, Alternative F	2.3 miles	9 & 10
BA-2	Sand Boils and Foundation Seepage	Backfill borrow excavation pit to a distance of 100 feet from the l/s toe or combination l/s slurry cutoff wall with stability berm 30 deep 1000 feet in length	500 feet	11

Notes:

1. Distance is very approximate and needs to be verified prior to final design.

**TABLE 1 (cont.)**  
SITES RECOMMENDED FOR RECONSTRUCTION

SITE NUMBER	PROBLEMS/CONCERNS	RECONSTRUCTION ALTERNATIVES	SITE LENGTH	PHOTO NUMBER
349-1	Seepage and Sand Boils in Irrigation Ditch	Stability Berm, Alternative G	1500 feet	13 to 15
501-8	Severe Seepage and Numerous Sand Boils	Seepage/Stability Berm, Alternative A or B	2000 feet	12
501-9	Seepage and Numerous Sand Boils	Seepage/Stability Berm, Alternative A or B	2500 feet	-
3-2	Seepage and Landside Slope Stability	Stability Berm, Alternative F	8000 feet	-
3-3	Seepage and Sinkhole Area	Backfill Ditch and "Sinkhole" Area with Drainrock	300 feet (Note 1)	-
150-8	Seepage and boils in irrigation ditch	Install drainage collector system, Alternative H	500 feet	-
150-9	Seepage and boils in irrigation ditch	Install drainage collector system, Alternative H	1100 feet	-
501-1A	Location of 1904 levee failure, boils on levee slope in 1986 and highly permeable levee and foundation materials	Construct seepage/stability berm, Alternative A or B	1200 feet	-
2098-10	Significant erosion and slumping of landside slope	Restore lower portion of landside slope with stonefill and slope protection	2500 feet	23
2098-10A	Unstable landside slope with stress cracks and scattered slumps in slope	Backfill or relocate irrigation ditch to provide stabilizing effect on levee	400 feet	24
2068-1	Landside berm deteriorating and causing decrease in levee stability	Restore landside berm and provide slope protection	2500 feet	25 & 26
2068-2	Landside and waterside berms deteriorating and causing decrease in levee stability	Restore landside berm and provide slope protection to both landside and waterside berms	1.9 miles	-

Notes:

1. Distance is very approximate and needs to be verified prior to design.

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**TABLE 2**  
**SITES RECOMMENDED FOR NON-FEDERAL REPAIR**  
**OR BANK PROTECTION**

SITE NUMBER	PROBLEMS/CONCERNS	RECOMMENDATIONS	SITE LENGTH	PHOTO NUMBER
999-5	Erosion and sloughing of lower portion of waterside slope	Place stonefill and riprap the lower portion of waterside slope	500 feet (Note 1)	16 & 17
2098-10	Significant erosion and slumping of landside slope	Restore lower portion of landside slope and provide slope protection	2500 feet	23
2068-1	Landside berm deteriorating and causing decrease in levee stability	Restore landside slope and provide slope protection	2500 feet	25 & 26
2068-2	Landside and waterside berms deteriorating and causing decrease in levee stability	Restore landside berm and provide slope protection to both landside and waterside berms	1.9 miles	-
2060-3A	Slope Failure	Excavate and reconstruct failed levee section	100 feet	29
2098-8	Large erosional scarps on waterside bank and portion of levee slope	Repair with rockfill and riprap slope protection	1500 feet	21 & 22

Notes:

1. Distance is very approximate and needs to be verified prior to repairs.

E. SACRAMENTO RIVER - RIGHT BANK LEVEE (R.D. 765, R.D. 307, R.D. 999, and R.D. 150)

This reach (Figures 2 and 3) includes approximately 17 miles along the right bank of the Sacramento River. South River Road (two-lane) runs along the crest of the levee along this entire reach.

1. EXPLORATIONS.

Available explorations for this reach include 6 borings performed during the phase three study. These included 2F-91-35, 35A, 36, 36A, 37, and 37A. The levee crown borings were drilled to a depth of 40 feet and the landside toe borings were drilled to a depth of 20 feet.

2. LEVEE AND FOUNDATION CONDITIONS.

The levee profile is shown on Figures 6 and 7. Based on the available boring data, the levee soils are typical of other levee soils along the Sacramento River. One of the three levee borings, 2F-91-35 indicate clean levee materials, ie poorly graded sand (SP). The other two borings indicate finer grained silty sand (SM) and silt with sand (ML). The foundation conditions are consistent and consist of silt (ML) to silt with sand (ML).

3. PAST PERFORMANCE.

Seven problem areas were identified during the phase one study. These sites are shown in profile on Figures 6 and 7. Site 999-1 was reported to be a site where seepage occurred during the 1986 flood. Site 999-3 is located just upstream of this site and was reported to have seeped several gallons a minute. Site 150-3 was reported to have been a boil site that occurred 100 feet from the levee during the 1986 flood. Site 150-5 was identified as a site that has seeped several times in the past during high water. Site 150-6 was a boil site approximately 600 feet from the levee that developed during the 1986 flood. Following the flood, the landowner installed a relief at the location of the boil. The well has not flowed since installation.

4. CONCLUSIONS AND RECOMMENDATIONS.

The above problems were discussed with local representatives during the phase three field inspection. In general, there haven't been indications of sand boils or instability of the levee during periods of seepage. While seepage has occurred during high river stages, it is judged that the overall stability of the levee in this reach is good. It is also noted that the elevation of the 1986 flood was approximately the same as the design flood level. Therefore, there are no recommendations for this reach.

F. SACRAMENTO RIVER - RIGHT BANK LEVEE (R.D. 3 and R.D. 349)

The levees in this reach (Figures 4 and 5) include approximately 19 miles along the right bank of the Sacramento River and extends from the confluence of Sutter Slough on the Sacramento River to the Grand Island Cross Road near the Corps dredge disposal area near the tip of Grand Island.

### 1. EXPLORATIONS.

Prior to this study only three explorations were performed along this reach. These were borings 2F-64-6 thru 8, drilled along the landside levee toe during explorations for bank protection projects. During the phase two investigations, borings were drilled. These were 2F-90-9, 9A, 10, 10A, 11, and 17. Four additional borings were drilled during the phase three investigation. These included 2F-91-3, 3A, 4, and 4A.

### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile is shown on Figures 8 through 10. The levee soils are composed predominantly of clean sand, ie fines content less than 12 percent. The foundation materials consist of variable layers of silt and clean sand, typically with clean sand underlying the upper silty material at a depth of 10 to 15 feet. The levee in this reach is typically 14 to 17 feet high, with the highest levee section located in the vicinity of reported problem site 3-9 where the levee height is approximately 24 feet. The 20-foot levee crown is a paved highway throughout this reach. Standard Penetration blow counts (N) in the levee sand varies typically between 3 and 10 indicating very loose to loose material. The characteristics of the foundation sand and silt deposits are of similar consistency. Levee slopes in this reach vary from 1V on 2.5H to 4.0H landside and 1V on 2H to 2.5H waterside.

### 3. PAST PERFORMANCE.

The levee along this reach has generally performed well. Only three sites were identified during the phase one study. The first, Site 3-1 was identified as an area of waterside slumping. The waterside slope at this location is 1V on 1.7H. The 1986 flood reportedly caused much of this damage.

Site 3-9 was identified as a three mile reach beginning just upstream of the Grand Island Cross Road and extending upstream. It was reported that seepage along this reach was indicated by reeds growing on the landside slope.

Site 3-10 was identified as a boil site. This was a site where two boils occurred in a toe ditch near a private residence. During the 1986 flood, the boils were reportedly sacked by local reclamation district forces and California Conservation Corps (CCC). Following the 1986 flood, the ditch was backfilled in compliance with a reclamation district order.

### 4. CONCLUSIONS AND RECOMMENDATIONS.

Site 3-1 was identified as a slumping site. The phase three field investigation revealed that the problem at this site is erosion. This site is in need of bank protection and has been identified as a potential bank protection site under the Sacramento River Bank Protection Project.

The levee at Site 3-9 consists of loose sand (SP). This material is susceptible to seepage. However, based on levee geometry, instability is not considered a potential problem. The maximum levee height is approximately 24 feet. However, the landside slope is relatively flat at 1V on 2.6H as determined by DWR surveys at boring location 2F-90-10. During flood conditions, the head differential between the river and the landside toe is a maximum of about 10 feet. During the phase three field inspection, the reeds reported along this reach were observed to exist along the entire landside slope. The reeds are located high on the levee slope and are not a result of levee seepage. In conclusion, although seepage does occur in this area during high water, it is believed that overall stability of Site 3-9 is adequate and

reconstruction in this reach is not considered necessary.

As discussed above, the toe ditch at Site 3-10, in which sand boils occurred during the 1986 flood, has been backfilled. This was a prudent measure taken by the local reclamation district and is considered an excellent solution to the problem. Future sand boils at this location are not anticipated. However, during any future floods, this area should be checked.

#### G. SACRAMENTO RIVER - LEFT BANK LEVEE (M.A. 9, R.D. 755, and R.D. 551)

This reach (See Figures 2 through 4) extends from just south of Freeport on the left bank of the Sacramento River for 17.7 miles. State Maintenance Area 9 (M.A.9) maintains the upstream 9 miles of this reach beginning at the town of Freeport. R.D. 755 maintains the next downstream 1.86 miles, and R.D. 551 maintains the remaining 6.85 miles along this reach. River Road, a two-lane paved road, is on top of the levee for all but the 1.86-mile portion of levee in R.D. 755 where the highway deviates from the levee. The levee along this reach varies from about 15 to 25 feet in height. The crown width varies from approximately 30 to as much as 60 feet wide. The levee slopes are fairly steep. The waterside slope varies from about 1V on 1H to 2.2H, but it is commonly around 1V on 1.5H. The landside slope is similar, varying from about 1V on 1.3H to 2.2H, but more commonly around 1V on 1.8H. Although no major damage occurred during the 1986 flood, a fair amount of riverside erosion and landside seepage and boils developed. In several locations, CCC and DWR maintenance workers sandbagged sand boils along the landside toe of the levee to halt piping of foundation materials. Boil locations are shown on the profile (Figure 11). Several sites were identified where bank erosion occurred during the 1986 flood. These locations should be repaired under normal operations and maintenance efforts and are not specifically addressed in this report. Some bank or levee erosion repairs were made following the 1986 flood.

#### 1. EXPLORATIONS

Prior to this study only two borings (2F-64-9 and -10) were drilled for bank protection investigations in 1964. Four borings (2F-91-30, 30A, 41, and 41A) were drilled in 1991 to evaluate typical levee and foundation conditions.

#### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile is shown on Figures 11 and 12. Although the exploration data for this reach is somewhat limited, the available data and levee performance during the 1986 flood indicate that the levee and foundation conditions are very similar to those upstream of Freeport where extensive explorations were conducted in the Greenhaven-Pocket Area of Sacramento. Those explorations revealed the levees are founded primarily on deposits of firm silt and clay. The levee materials consist predominantly of clean sand dredged from the Sacramento River with smaller amounts of silt. The levee soil samples tested revealed clean and very uniform fine sand. Laboratory gradation analyses on two representative samples collected during the 1991 exploration program classified these soils as poorly graded sand (SP) with fines contents of only 4 and 5 percent. The foundation samples tested classified as silt (ML) or sandy silt (ML).

### 3. PAST PERFORMANCE.

During the 1986 flood several problems developed along this 17.7 mile reach. Several erosional sites developed along the waterside slope. Most of this damage has been repaired. One site, Site 551-3 was noted during the phase one study as in need of bank protection. Several boils occurred along a 6800-foot reach (approx. R.M. 43.8 to 45.1). As indicated on Figure 11, additional boils developed at various locations during the flood between about R.M. 38 and 41.7. These sites are identified as M.A.9-2A through MA9-5. The sand boils, which generally occurred within a few feet of the levee toe were sacked with sandbag chimneys by CCC and DWR maintenance personnel. The sandbag chimneys were effective in controlling piping of foundation material.

### 4. CONCLUSIONS AND RECOMMENDATIONS

As discussed above several sand boils occurred along this reach during the February 1986 flood. Only diligent flood fighting efforts prevented possible levee failure. However, emergency measures should not be depended upon to prevent levee failure during future floods. Because of the significant number of sand boils occurring near the landside toe in this reach and the similarity of soil conditions just upstream, there is sufficient justification to provide some means of seepage control. The levee and upper foundation materials are very susceptible to internal erosion. Therefore, it is recommended that seepage control measures be constructed in the areas where a significant numbers of sand boils developed in 1986. The sites identified are shown on Figure 11. The land adjacent to the levee is primarily agricultural. Therefore, there is sufficient clear space next to the levee for construction of a landside seepage/stability berm. Alternative A or B should be used for these sites. The berm will improve overall stability of the levee due to the vulnerability of the levee to progressive landside slope failure due to levee saturation and decrease the potential for foundation piping. The length of the seepage portion of the berm is shorter than those identified in other areas because the susceptible foundation soils are relatively near the surface.

Site 755-3 was identified on Randall Island as experiencing significant amounts of seepage. However, the seepage was reported to be generally confined to a drainage ditch, which when filled with seepage water controlled the boils. Future sand boils in this area can be controlled by backfilling the ditch. One site identified at the northern side of the island experienced a sand boil approximately 30 feet from the levee toe. This boil was controlled with a sandbag chimney. The boil was isolated and is not considered a widespread problem in this area. Therefore, other than monitoring during future flooding, no other recommendations are made for this area.

### H. SACRAMENTO RIVER - LEFT BANK LEVEE, HORSESHOE BEND, and THREEMILE MILE SLOUGH (R.D. 341 and R.D. 1601)

This reach of the flood control system includes 9.74 miles of levee protecting Sherman Island (R.D. 341) from the Sacramento River, Horseshoe Bend, and Threemile Slough (Figure 5). In addition, this reach includes the 2.47 miles of levee along the east bank of Threemile Slough and a short reach of Sevenmile Slough which protects Twitchell Island (R.D. 1601).

### 1. EXPLORATIONS.

Five borings (5F-1 through 5F-8) were performed by the Corps of Engineers in 1955 along the west side of Threemile Slough (R.D. 341) to evaluate levee settlement and peat thickness. Fifty additional borings (100-128, and 28-49) were performed by the California Department of Water Resources in 1956 during the Salinity Control Barrier Investigation. During the phase two study, three borings (2F-90-1 thru 3) were drilled along the east bank levee of Threemile Slough. During the phase three study, four borings (2F-91-1, 1A, 2, and 2A) were drilled along the left bank levee of the Sacramento River and Horseshoe Bend.

### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile is shown on Figures 13 through 15. Levee soils along the Sacramento River and Horseshoe Bend are primarily sand and silt soils which have been dredged from the Sacramento River and Threemile Slough. As indicated on Figure 15, the foundation materials consist of interbedded deposits of sand, silts, clays, and peat of varying thicknesses. The peat deposits vary in thickness from about 20 to 40 feet. The levee height in this reach varies from approximately 10 to 20 feet. The landside and waterside slopes are variable and range from approximately 1V on 2H to 3H.

The levee along the west bank of Threemile Slough varies from about 10 to 12 feet in height. The levee slopes are typically 1V on 2H waterside and 1V to 2 to 3H landside. Based on available exploration data, the levee material consists of clean sand. The upper foundation to a depth of about 10 to 15 feet consists of peat. Sand underlies the peat to a depth of at least 30 feet.

The levee and foundation materials along the east bank levee of Threemile Slough (R.D. 1601) consists primarily of sand. The levee height is typically 15 feet with both slopes approximately 1V on 2H. Although no water movement was detected seeping along this reach during site inspections, ponded water exists along the toe for most of the entire reach. Cattails and other water loving plants thrive up to approximately 200 feet from the levee toe.

### 3. PAST PERFORMANCE.

The levees in the Sacramento River portion of this reach were raised from 1 to 5 feet in 1954. During this construction and again in 1955 several levee slope failures occurred primarily between approximately R.M. 3.75 and R.M. 4.5. The 1955 failures involved up to 4 feet of slumping of the levee crown and bulging of the landside toe area. Site 341-5, which is within this reach, is approximately 1/2 mile in length. Again in 1965, additional slumping occurred in this same area. As indicated on Figure 15, this is also an area of thick peat deposits which likely contributed to the failures. No serious slumping has been reported since the 1965 repairs were completed. As part of the 1965 repairs, the county road was moved off of the levee crown (Photo 1).

Seepage has been reported at three other sites including 341-2, 341-3, and -3A. A 1930's levee failure (Site 341-4) occurred in Horseshoe Bend. The levee failure resulted in a large landside scour pond (Photo 3). It was reported in the phase two study that Site 341-4 seeps all year. Seepage was also reported along the 2-mile reach of the west levee of Threemile Slough. This reach is identified as Site 341-1. The east bank levee of Threemile Slough (Site 1601-1) has a history of slumping following 4 to 5-foot raising in 1954. Numerous stability and subsidence problems continued to occur in this reach until it was completely turned over to the State Reclamation Board in 1955. In the early 1980's a low toe berm

approximately 100 feet wide was constructed with dredge deposits in the southern half of the reach. Seepage still occurs throughout most of the reach between the southern tip of Twitchell Island and the confluence of Threemile and Sevenmile Sloughs.

#### 4. CONCLUSIONS AND RECOMMENDATIONS.

Several relatively short reaches of past seepage or instability were reported in this portion of the study area. However, most of these areas are small and considered maintenance problems and not considered a serious threat to levee stability. In the phase two report, seepage control was recommended at Site 341-1. During the phase three field investigation, the landowner reported the peat soils at the ground surface do become saturated and pond water in the winter months and become dry in the summer. The landowner, who has lived at this location for 30 years, indicated that although this area is wet much of the year, he was not aware of any boils or slope failures along any portion of this reach. The recommendation in the phase two report was for a shallow ditch at the toe of the landside slope to drain collected water to sumps or other appropriate facilities. The landside slope varies from about 1V on 2H to 4H, and averages about 1V on 3H. Seepage does exist in this area. However, it is judged to be innocuous. During high water, seepage that occurs through the levee emerges in the upper portion of the foundation and safely flows over the relatively flat upper peat and silt foundation soils of the levee and ponds in low areas beyond the levee toe (Photo 2). It is believed that the seepage occurring in this area does not pose any major risk to levee stability. Therefore, no reconstruction is recommended in this reach.

Site 341-2 is a location that seeps into a shallow drainage ditch adjacent to the levee toe just west of the Outrigger Marina at the northern tip of Sherman Island. This seepage condition developed in 1990 after PG&E replaced a gas line through the levee. Since then this area has been monitored by reclamation district and PG&E personnel. This condition is under control of the local reclamation district and is considered to pose no current threat to levee stability.

Waterside bank erosion and small seeps were reported for Sites 341-3 and -3A. As with all bank erosion, this should be monitored and repaired as necessary by the local reclamation district. During the third phase inspection, no visible signs of seepage were detected. If seepage is a problem in these short reaches, they should be monitored and seepage modification measures if necessary should be within the capability of the local reclamation district.

Site 341-4 is the site of a 1930's levee breach. A very large scour pond remains in this location. It is likely that seepage from Horseshoe Bend enters into the pond through the levee foundation. However, there were no indications of near surface seepage during the site inspection. The levee crown at this location is approximately 100 feet wide. No repairs are recommended.

Site 341-5 has a history of slope failures following early years of levee raising. The levee landside slope still shows remnant undulations from slumping in the early 1950's. Recreationists use this road for access to the river, worsening the already deteriorated condition of the levee crown. The levee crown in this area has several potholes up to a foot deep. The levee crown is in need of regrading and gravel surfacing. To prevent continued damage to the levee crown, access to this stretch of levee by recreational vehicles should be denied by the use of locked gates. However, levee stabilization with a landside toe berm as recommended in the phase two report is not considered necessary.

At Site 1601-1, foundation seepage saturates the entire area within approximately 200 feet

of the levee toe. No signs of boils were evident during the phase three inspection. The greater concern is for slope stability. Although no signs of slope instability were evident during the inspection, the conditions for instability are apparent. During the inspection, the landside slope was damp up to one foot above the toe contact. The levee and foundation soils are predominantly sand. The landside slope is relatively steep and present site conditions indicate seepage problems. Some shallow stability is afforded by the dense grassy landside slope. However, there is sufficient concern about stability throughout this reach to warrant a landside seepage/stabilizing berm. The berm (Alternative C) will not reduce the overall quantity of seepage, but it will improve the stability of the levee and decrease the potential for foundation piping. The cutoff wall alternative is not recommended in this area. The water level is always above the landside toe in this portion of the delta and therefore any hydraulic fracturing of the levee during construction can cause a catastrophic failure and flooding of the island.

I. SACRAMENTO RIVER - LEFT BANK LEVEE (R.D. 369, R.D. 554, R.D. 556 and Brannan-Andrus Levee Maintenance District)

This reach (Figure 4 and 5) includes approximately 21 miles along the left bank of the Sacramento River downstream of Meadows Slough, including a short reach of the right bank levee (Brannan Island) of Threemile Slough and Sevenmile Slough. R.D. 369 and R.D. 554 maintain 0.80 and 1.15 mile reaches respectively on the left bank of the Sacramento River. R.D. 556 maintains the Sacramento River levee from the cross levee upstream 5.7 miles to the confluence of Georgiana Slough and the Sacramento River. Brannan-Andrus Levee Maintenance District maintains the remaining 13.3 miles of the Sacramento River levee downstream of the cross levee including a portion of Threemile Slough.

1. EXPLORATIONS.

In 1990, two borings, 2F-90-8 and 8A were drilled along the Sacramento River in R.D. 556. These borings were drilled in locations where seepage and boils have been reported during high river conditions (Site 556-1). These conditions are described in the following paragraphs.

2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile is shown on Figure 16. The levee in this reach of the Sacramento River is typically 15 feet in height with a crown width of about 20 feet. The levee crown is paved and in excellent condition. Landside and waterside slopes are variable, typically ranging between 1V on 2H to 3H. Borings 2F-90-8 and 8A indicate the levee materials consist of loose to medium dense sand and silty sand while the foundation is similar with intermittent layers of clay or silt in the upper 10 feet. The foundation material below about 15 feet to at least the depth of boring 2F-90-8 (66 feet below original ground surface) consists of clean sand deposits with minor amounts of gravel to 1/2-inch diameter.

3. PAST PERFORMANCE.

The 21 mile levee reach along the left bank of the Sacramento River has performed well. The reach between the cross levee and Threemile Slough is not included in profile since no problems have been reported in this entire reach. The only reach identified as having any problem was the 1700-foot reach identified as Site 556-1. This site was identified

as having significant seepage, even during normal water levels. Sand boils occurred in February 1986 at this location in a man-made ditch perpendicular to the levee. However, the landowner reported that since the ditch was backfilled, no other problems have occurred.

#### 4. CONCLUSIONS AND RECOMMENDATIONS.

The phase two report recommended a series of remedial repairs including landside slope protection and relief wells at Site 556-1. Discussions with the landowner during the phase three site inspection revealed that there has not been a history of seepage along the levee toe. The only problem in this area was the 1986 boil that developed in a ditch that was oriented perpendicular to and near the levee toe adjacent to the landowners home. Sometime after the 1986 high water, the ditch was backfilled and no further problems have occurred. In general, this reach of the study area has performed well. Therefore, reconstruction in any part of this entire reach is not considered necessary.

#### J. GEORGIANA SLOUGH - LEFT BANK LEVEE (R.D. 563) AND RIGHT BANK LEVEE (R.D. 556 & BRANNAN ANDRUS LEVEE MAINTENANCE DISTRICT)

Georgiana Slough originates just below Walnut Grove on the north and terminates at the North Fork of the Mokelumne River at the downstream end. The left bank levee, maintained by R.D. 563 is approximately 12 miles in length. The right bank levee is maintained by R.D. 556 (northerly 5.47 miles) and the southerly 6.02 miles are maintained by the Brannan Andrus Levee Maintenance District (Figures 4 and 5). The left bank levee is the only project levee that protects Tyler Island (R.D. 563) from flooding. The North Fork Mokelumne River levee to the east is a non-project levee. That levee failed in February 1986 and caused flooding of Tyler Island.

##### 1. EXPLORATIONS.

Only five previous borings were available along Georgiana Slough. These included three left bank borings, 2F-66-3 and -4 by the COE and TI-F3 (toe boring) drilled by the DWR. Borings 2F-66-1 and 2F-66-2 were drilled along the right bank of Georgiana Slough. Seven recent borings were also drilled along the right bank of Georgiana Slough as part of this study. These borings included 2F-90-6, 7, and 7A and 2F-91-43, 43A, 44, and 44A. Six recent borings were drilled along the left bank. These included 2F-90-4, 4A, 5, 5A, 2F-91-42 and 42A.

##### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figures 17 through 19. Based on surveyed cross sections, the levees along the left bank of Georgiana Slough range in height from about 10 to 13 feet. The landside slopes are typically 1V on 2H to 2.5H. The waterside slopes are more variable ranging from 1V on 2.5H to 3H. Borings 2F-90-4 and 2F-90-5 located on the left bank levee in the southern portion of this reach near site 563-4, indicate the levee soils consist primarily of clean sand. Gradation analyses of samples collected from these borings indicate a fines content in the levee material as 9 and 6 percent respectively. The foundation for a depth of about 8 to 10 feet consists of organic clay and silt which is underlain by clean sand to an undetermined depth. Borings upstream of this area indicate similar levee soil conditions. However, the foundation soils are general fine grained

consisting of sandy silt and organic clay.

### 3. PAST PERFORMANCE.

In 1986, inundation of Tyler Island following the 1986 breach along the North Fork Mokelumne River caused landside slope damage due to wave action. PL-84-99 repairs were made to several reaches along the Georgiana Slough levee to repair this damage. Seepage has been reported along portions of both the left and right bank levees of Georgiana Slough, particularly at the southern end. These are described below.

Site 563-1, was identified upstream of the Isleton Bridge in the phase two study. Based on field observations made in the phase three investigation, this site should have been located downstream of the Isleton Bridge as shown on Figure 18. It extends for about 1000 feet downstream of the Bridge. The levee material in this area consists of clean sand and although not apparent from the two borings at this location, it was determined during the phase three site inspection that the upper foundation soils also consists of clean sand. Seepage emerges in this reach from the lower portion of a mildly sloping and undulating sand berm. Damp soil conditions and water loving plants exist in an area about 40 feet from the levee landside toe (Photo 4).

Site 563-2 is about 750 feet in length and is located on the left bank. The levee in this reach consists of very clean and loose sand. A portion of the landside slope has been excavated apparently for the purpose of providing an access road along the levee toe. As a result, several sloughs of the levee landside slope have occurred. In addition, seepage occurs along the landside toe of the levee. Cattails and standing water exists along the toe throughout most of this reach (Photos 5 and 6). This condition is considered a potential threat to levee stability.

Site 563-3 on the left bank was identified in the phase one study as being a short reach of seepage related problems. However, during the phase three field inspection, any indications of past seepage in this general area were not apparent. If this is an area of seepage related problems, it is judged that the situation can be remedied during routine maintenance by the local reclamation district.

Site 563-4, approximately 4700 feet in length, is located on the left bank near the downstream end of Georgiana Slough. Reeds and other water loving plants thrive along the landside toe throughout this entire reach. Most of this seepage is apparently intercepted by the irrigation ditch that exists very close to the landside toe in some areas (Photo 7).

Site 556-2, is located on the right bank of Georgiana Slough within R.D. 556. This is a reported seepage area which extends upstream approximately 4800 feet of the cross-levee which separates R.D. 556 and Brannan-Andrus Levee Maintenance District. Seepage has been reported up to 200 feet into the field at this location. The seepage is significant enough to prevent agricultural use of the field in this area. During the phase three site inspection, seepage was flowing in an irrigation ditch adjacent to the levee toe and wet soil was apparent at least 50 feet from the levee toe (Photo 8).

In the Brannan-Andrus Levee District portion of the right bank levee, seepage has been reported to be a problem in an 8000-foot reach (approx. channel mile 1.5 to channel mile 3.8) downstream of the Sewage Disposal Ponds located southeast of Isleton. This is identified as Site BA-1. During the phase three site inspection, the foundation just beyond the levee toe was saturated in several areas. One area about 500 feet in length near channel mile 2.5 was experiencing particularly heavy seepage during the phase three inspection. Seepage at this location was observed exiting from about 1 to 2 feet up on the levee slope as well as at the

levee foundation contact (Photos 9 and 10). A recently constructed toe ditch was excavated in this reach by local interests to channel seepage water to a nearby culvert.

A second site, BA-2, not identified in the phase one study, is a location where three boils were reported in 1991. Waterside bank erosion was also noted in this location during the phase three field investigation. That problem was considered of immediate concern because it was adjacent to where the boils occurred in 1991. The waterside bank erosion has since been repaired by local representatives. However, this 500-foot reach is of concern. Material borrowed for the adjacent railroad embankment which descends from the right bank levee, was apparently borrowed from adjacent to the levee. This area developed into a swamp with a dense growth of trees. A sandbagged chimney is still in place where the boils developed in 1991 (Photo 11).

#### 4. CONCLUSIONS AND RECOMMENDATIONS.

At Site 563-1, the area beyond the levee landside toe should be cleared and a seepage berm (Alternative C) should be constructed over this 1000-foot reach. This will minimize the potential for foundation boils and associated piping.

At Site 563-2, measures should be taken to reduce the potential for slope instability and foundation piping. The landside slope in this area is oversteepened and should be flattened. During the phase three inspection, exposed landside scarps indicated that the levee material consists of clean sand and therefore is very susceptible to instability during flood conditions. The landside slope should be stripped of all vegetation and reconstructed to 1V on 3H. This will prevent further sloughing and greatly improve overall stability and reduce the potential for foundation piping.

Site 563-3 was identified in the phase two report as a seepage site. However, during the phase three investigation no indications of seepage were observed. Therefore, there are no recommendations for reconstruction for this site.

A slope stability analysis of one levee cross section was performed in the phase two study at Site 563-4. The result of the analysis was that the levee had a minimum factor of safety of 0.8. Theoretically, failure would have already occurred. A review of the phase two report concluded that assumptions used including soil shear strength and assumed water surface were overly conservative. A reanalysis performed during phase three study using resulted in a minimum factor of safety of 1.27 (Figure 19A). This is slightly less than normal criteria of 1.4. However, given the conservatism used in this analysis and performance history, the slope stability is judged as acceptable. The history of seepage and site conditions, however, do indicate that foundation conditions are susceptible to piping. As can be seen on the levee profile in Figure 18, clean sand deposits underlie the upper foundation silt deposits. Irrigation ditches can intercept the foundation clean sand layers and result in significant seepage and/or foundation piping. Some portions of the irrigation ditch in this area are located near the levee toe. To decrease the potential for piping of foundation material, it is recommended that where the existing irrigation ditch is closer than 75 feet to the levee toe, it be backfilled and relocated a distance of at least 75 feet from the levee toe.

A series of relief wells were recommended in the phase two report for Site 556-2. Remedial repairs are recommended for this reach. However, relief wells are not considered the best solution. Relief wells can be effective in reducing uplift pressures beneath relatively impervious soil strata. But relief wells would do little for near surface foundation or through levee seepage. Seepage analyses performed for this site indicated a seepage exit gradient of approximately 0.68. Corps guidelines recommend a seepage berm where the exit gradient

exceeds 0.50. Further analysis at this site showed that the seepage exit gradient can be reduced to 0.52 with a 35-foot wide seepage blanket. The seepage berm (Alternative E) will control foundation seepage near the levee toe as well as improve overall levee stability. Prior to constructing the berm, clearing of the heavily vegetated slope and cleaning and backfilling of the irrigation ditch near the levee toe will be necessary.

Seepage has been reported to be chronic at Site BA-1. This portion of Georgiana Slough was not part of the phase two study. The field inspection at this site revealed that extensive seepage is occurring through the levee. This seepage is particularly threatening to levee stability. The recommendation at this site is for a landside stabilizing berm (Alternative F).

Site BA-2 is considered a potential weak point in the levee system. In 1991, boils developed which carried fine sand. This area is heavily overgrown and the cavity left by the borrow excavation is of unknown depth. Inspection during floods can be very difficult in this area because of the dense vegetation and swampy condition. Therefore, it is recommended that this area be backfilled to the adjacent ground level to a distance of 100 feet from the levee toe. Since there is a very dense growth of trees in this area, trees and other vegetation within 100 feet of the levee will need to be removed prior to backfilling this area. A most likely source of material for this purpose is the railroad embankment. The width of backfill required is approximately 500 feet. This is an environmentally sensitive area. Therefore an alternative design may be required. A slurry cutoff could be constructed through the levee. However, the length of the wall must be longer (estimated 1000 feet) to prevent end around seepage effects into the borrow pit.

#### K. STEAMBOAT SLOUGH - RIGHT BANK LEVEE (R.D. 349 and 501)

There are a total of approximately 11.2 miles of levee in this reach (Figure 4). The right bank levee of Steamboat Slough is maintained by two reclamation districts. R.D. 349 (Sutter Island) maintains the upstream 4.35 miles beginning at the confluence of the right bank levee of the Sacramento River to the confluence of Sutter Slough at downstream limit. R.D. 501 (Ryer Island) maintains the levee in the lower 6.85 miles from confluence of Sutter Slough downstream to the confluence of Cache Slough.

##### 1. EXPLORATIONS.

In 1956, three borings (2F-56-1 through -3) were drilled at the landside toe of the levee near the southern tip of Sutter Island to investigate seepage problems. In 1979, three borings (TH-25.4RT, -25.5RT, and 25.7RT) were drilled along the right bank levee of Steamboat Slough (Sutter Island) to evaluate levee and foundation soil conditions for bank protection. In 1991, seven borings (2F-91-18A, 22, 22A, 23, 23A, 28, and 28A) were drilled for this study.

##### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figures 20 and 21. Cross section surveys were performed along the right bank levee of Steamboat Slough along both Sutter Island and Ryer Island. This data indicates that the levee along Sutter Slough ranges from 12 to 21 feet high and averages about 15 feet high. The crown width varies from 21 to 37 feet and averages about 25 feet. The slopes range from 1V on 2.9H (typ. 1V on 2.5H) landside and 1V on 1.8H to 2.4H (typ. 1V on 2H) waterside. The levee along Ryer Island is higher, ranging from 16 to 25 feet (typ. 20 feet) high. The crown width varies from about 30 to 52 feet (typ. 40 feet). The landside slope ranges from 1V on 2.8H (typ. 1V on 2H) and

the waterside slope ranges from about 1V on 1.5H to 4.0H (typ. 1V on 2.5H).

Drill logs shown on the profiles clearly show that the levee soils along the entire reach consist primarily of clean fine sand. The foundation soils are generally fine grained ranging from fat clay (CH) and organic clay (OH) to silt (ML). The exception to this is the foundation condition near the tip of Sutter Island, which is discussed in more detail below.

### 3. PAST PERFORMANCE.

Seepage has occurred in the past at some locations during high water. The most serious seepage has occurred at the southern tip of Sutter Island. This is identified as Site 349-1. During the 1955-56 flood, a sand boil developed beyond the levee toe at a location approximately 125 feet from the left bank levee of Sutter Slough and 125 feet from the right bank levee of Steamboat Slough. Based on foundation conditions determined from the 1956 explorations, three 25-foot deep relief wells were installed along the landside toe in 1956 to control uplift pressures and reduce the potential for foundation piping. One relief well is located between the levee and a 3-foot deep irrigation ditch at the tip of the island. The second relief well is located approximately 190 feet upstream along Sutter Slough just above the levee toe. The third relief well, also located just above the levee toe is located approximately 160 feet upstream along Steamboat Slough. Followup inspections through at least 1958 revealed that all three relief wells produce water. However, an inspection made about this same time period reported that a small boil had developed landward of this area.

Site 501-8 (Ryer Island) was identified in the phase two study as a 2000-foot reach of severe seepage in the past (Photo 12). It was reported that during the 1986 flood, boils occurred at the landside toe of the levee but did not require sandbagging. It was reported by one representative that there were so many boils in this area that sandbagging would have been extremely difficult. Fortunately, ponded water in the area of the boils produced enough backpressure to the point where piping from the boils subsided.

Site 501-9 (Ryer Island) was identified in the phase two study as a 2500-foot reach of levee on the right bank of Steamboat Slough where heavy seepage was reported in the past. This site is located at approximately channel mile 1.5. The landowner reportedly installed a french drain in a portion of this area in an attempt to cure the problem. It was reported that seepage occurring in this area in 1986 was not as bad as previous years. It is believed that the drain may have provided some improvement.

### 4. CONCLUSIONS AND RECOMMENDATIONS.

A local representative of RD 349 reported that the biggest problem along the Sutter Island portion of this reach is Site 349-1. A sand boil occurred in 1986 in the irrigation ditch next to the levee landside toe (Photo 13). The boil was in close proximity to the center relief well. It was reported that sand bags were used to create a chimney around the boil. During the site visit, water was noted seeping from at least one point source in the ditch near the center relief well at a rate of approximately 10 gpm. The three relief wells were found to be in poor condition. No flow was occurring from any of them. Stagnant water was visible at a depth of about 1 foot from the surface in the center well and the well along Steamboat Slough (Photo 14). The well along Sutter Slough was completely filled with dirt (Photo 15). Apparently no maintenance has been performed on these wells in recent years. A factor of safety for slope stability of only 0.9 was determined during the phase two study. The design water surface used in the phase two study was 5 feet higher than the design water surface and very little exploration data was available for the analysis. Based on additional exploration

data collected during the 1991 explorations, and using the actual design water surface, the minimum factor of safety was determined to be 1.09 (Figure 20A). This is still significantly less than the factor of safety of 1.4 required by Corps criteria. Therefore, it is recommended that a stability berm (Alternative G) be constructed at this location. The limits of the berm and backfilled drain should be approximately 750 feet along Sutter and Steamboat Sloughs. These limits are based on judgement of the levee geometry and site conditions. In addition, the relief wells should be cleaned out, extended through the proposed berm, and the irrigation ditch should be lined with a geotextile, backfilled with gravel and a collector pipe should be installed.

The only exploration performed at Site 501-8 was a 35-ft deep boring (2F-90-18A) at the landside toe of the levee. This boring may not accurately depict general foundation conditions at this site. Since several boils occurred at this location, it is anticipated that the upper foundation soils at this site would consist predominantly of clean sand deposits. However, boring 2F-91-18A indicates the upper 30 feet consists of silt. It is possible that the boring at this site is not representative of the prevailing foundation conditions. Additional explorations could be conducted at this site to refine the available levee and foundation information. However, a possible reduction in the length of modifications in this reach would not justify the comprehensive investigations necessary to determine precise foundation conditions for the purpose of reducing the length of modification. Therefore it is recommended that modifications in this reach extend for the length identified in the phase two study. The recommendation for Site 501-8 will be the same as that for Site 501-9 discussed below.

A flownet analysis (Figure 21A) was performed for Site 501-9. The calculated seepage exit gradient equates to a factor of safety against piping of 2.66. This is slightly less than 3.0, the value that would normally be considered acceptable. The landside slopes at Sites 501-8 and 501-9 are 1V on 1.8H and 1V on 2.0H respectively. From a stability standpoint, these slopes are relatively steep. Given the steepness of these slopes and the seepage conditions, it is recommended that a seepage/stability berm (Alternative A or B) be constructed at both sites. Installation of the berm will not reduce the overall seepage quantity. It will, however, decrease the potential for foundation piping and improve overall levee stability.

#### L. STEAMBOAT SLOUGH - LEFT BANK LEVEE (R.D. 3)

Steamboat Slough extends from the right bank of the Sacramento River downstream to the cross road near the tip of Grand Island (R.D. 3). The length of the left bank levee is approximately 11 miles.

##### 1. EXPLORATIONS.

Two 9-inch bucket auger borings (2F-64-11 and -12) were drilled along the levee landside toe during bank protection studies in 1964. During the phase two study, nine auger borings (2F-90-12 thru -16) were drilled through the levee crown and toe. Two additional borings (2F-91-27 and -27A) were drilled in 1991 during the phase three study.

##### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figures 22 and 23. Levee soils along this reach are predominantly clean poorly graded fine to medium sand (SP) with

some sandy silt (ML). Standard Penetration blow counts (N) indicate the levee sand is typically very loose to loose. Foundation soils are similar, but with scattered deposits of clay (CL) and organic clay (OH) and silt (ML). Although the levee soils are particularly vulnerable to through seepage, the landside slopes are relatively flat and are in general considered stable. Twenty-six surveyed cross sections indicate the landside slope ranges from 1V on 2.1H to 5.3H and averages 1V on 3.2H. The levee height ranges from about 16 to 28 feet and averages 21 feet. This reach of levee is a two lane paved highway with an overall width from approximately 25 to 35 feet.

### 3. PAST PERFORMANCE.

Past problems along the left bank levee of Steamboat Slough have generally been bank erosion and sand boils in some locations during high water. Five past problem areas were identified during the phase two study. The first of these is Site 3-2. This site extends from the Sacramento River downstream for 1.5 miles. Heavy seepage was reported along this reach during the February 1986 flood. According to one local representative, seepage emerged at the levee foundation contact. The Corps participated in an inspection of this reach during the 1986 flood and did observed seepage exiting the levee slope. Boring 2F-90-16 in this area penetrated levee sand which was very uniform and in a laboratory gradation analysis showed a fines content of only 1 percent. This material is particularly vulnerable to seepage and piping.

Seepage has also been reported at Site 3-3 which extends south from the confluence of Steamboat and Sutter Slough for about 1/2 mile. The levee landside slope in the area of Site 3-3 varies from about 1V on 3H to 3.8H. The levee height is typically around 15 feet. A boil and sink hole was also reported at the southern end of this reach. The boil and "sinkhole" was inspected during the phase three field investigation in June 1992. The boil, which is located in an irrigation ditch about 100 feet from the levee was not active at the time of the inspection. The reported "sinkhole," was reportedly filled in the past and continues to reoccur. It is located about 75 feet from the landside levee toe and approximately 200 feet downstream of the reported boil and is overgrown with weeds and brush and difficult to evaluate. It is conceivable that during very high water stages in the slough, sand material is being carried into a nearby irrigation ditch and causing a reoccurring void in this area.

Site 3-4 was identified in the phase two report as the location of two sand boils. Record of one of the boils was documented in July 1987 in Sacramento District correspondence files. The Corps' recommendation to the reclamation district at that time was to provide a gravel drain and backfill for the irrigation ditch in which the boils were occurring. The phase two study reported that signs of one of the boils is still visible. The other boil identified in 1987 was not visible and has apparently been repaired.

At Site 3-6, seepage has been reported emerging from the levee below two large diameter discharge lines penetrating the levee section. Runoff has been reported to undercut the foundation of the pumphouse adjacent to the levee. During the phase three site inspection, exposure of the foundation footing was apparent, however no indications of seepage were observed.

The waterside bank at Site 3-8 is heavily eroded due to wave action. This reach is in need of bank protection.

### 4. CONCLUSIONS AND RECOMMENDATIONS.

Site 3-2 is considered highly susceptible to serious damage during floods. Sand boils

beyond the levee toe have been reported in this area. However, the concern for levee stability resulting from through levee seepage is of greater concern. The levee geometry as described above and the highly permeable nature of the levee soil make it susceptible to through levee seepage and landside slope failure. Therefore, based on performance in this reach and site conditions, a landside stability berm (Alternative F) is recommended.

Although seepage has been reported in the reach identified at Site 3-3, the levee along this reach is believed to be relatively stable. The boil that occurs at the southern end of this reach occurs in an irrigation ditch. The ditch should be backfilled with drainrock. Geotextile fabric should be used to line the ditch prior to drainrock placement. An approximation of the length of backfill required is 300 feet, but the exact limits of the backfill should be based on a close examination of the field conditions. Although seepage will still occur during high water, the potential for piping of foundation soil will be greatly reduced. The sink hole area should also be backfilled. An appropriate course of action for the sinkhole, would be to backfill it as well with drain rock. Appropriately sized drain rock will decrease the potential for future erosion of material in this area due to levee underseepage.

Site 3-4 was identified as a site where two boils have occurred in the past. One of the boils was apparently corrected by Reclamation District 3 in 1987 by installation of drain rock and a collector pipe. The ditch at the second boil site had been backfilled and relocated further away from the levee. Therefore, the location of the second boil is no longer considered a problem.

At Site 3-6 seepage has been reported to emerge from two discharge pipelines that penetrate the levee. A seepage path apparently exists adjacent to pipes during high water stages in Steamboat Slough. This condition is considered primarily a nuisance brought about by the installation of the pipes through the levee. This problem could be rectified by designing a seepage collector system in this location and diverting the seepage away from the pumphouse or constructing an impervious cutoff around the pipe on the waterside bank.

As mentioned in paragraph 3, Site 3-8 has experienced extensive damage of the waterside bank due to wave action. This site and any other locations where bank erosion is occurring should be repaired under normal O&M procedures by the reclamation district.

#### M. SUTTER SLOUGH - RIGHT BANK LEVEE (R.D. 501 and R.D. 999)

This reach of levee includes 2.33 miles of the right bank of Sutter Slough south of the confluence of Miner Slough (R.D. 501) and 3.74 miles of levee of the right bank of Sutter Slough (R.D.999) north of the confluence of Miner Slough (Figure 4).

##### 1. EXPLORATIONS.

The only exploration available for this reach is boring 2F-64-1 drilled in 1964 for bank protection investigations. Since no problems were identified in the phase one study for this reach, no further explorations were conducted during the phase three study.

##### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 24. Survey cross sections were completed for this reach every 1000 feet north of Miner Slough and every 2000 feet south of Miner Slough. According to this data the levee height varies from 15 to 18 feet. The crown width varies from 26 to 44 feet and averages 35 feet. The landside slope ranges from 1V on 2H to 4H (average 2.8H). The water side slope ranges from 1V on 1.8H to 4H

(average 2.5H). Except for the reach between Miner Slough on the south and Oxford Road (Salano Road on Figure 4) on the north, the levee crown is asphalt paved. Based on boring 2F-64-1, the foundation soils are fine grained consisting mainly of silt (ML).

3. PAST PERFORMANCE.

No problem areas were identified during the phase one investigation in this entire reach.

4. CONCLUSIONS AND RECOMMENDATIONS.

There are no recommendations for reconstruction in any portion of this study reach.

N. ELK SLOUGH - LEFT BANK LEVEE (R.D. 150)

The left bank levee along Elk Slough extends from the confluence of the Sacramento River at the upstream end to the confluence of Sutter Slough at the downstream end (Figure 3). The levee along this reach is approximately 9.4 miles in length.

1. EXPLORATIONS.

Explorations conducted prior to 1991 include two borings. These were 2F-56-1 and 2F-56-2. Both borings were drilled adjacent to the levee landside toe irrigation ditch. Seven additional borings including 2F-91-33, 33A, 34, 38, 38A, 39, and 39A) were drilled in 1991 during the phase three investigation.

2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 25. Based on available information, the levee height in this reach varies from approximately 12 feet at the upstream end to a maximum of about 22 feet at the downstream end. The levee crown is from about 14 to 18 feet wide. Portions of the levee crown are asphalt paved and portions are gravel surfaced. The landside slope is generally mild varying from about 1V on 3H to 4H. The waterside slope is relatively steep at about 1V on 1.6H and heavily overgrown with trees and other vegetation. The levee and foundation soils in this reach are similar. Explorations indicate the levee and foundation soils at the upstream end are generally fine grained. The levee in the upstream borings were identified as firm to stiff silt (ML) and clay (CL), while the foundation materials are soft to firm clay (CL) or loose silt (ML). At the downstream end, in the vicinity of Sites 150-8 and 150-9, the levee and foundation soils consist primarily of very loose to loose silt (ML) to fine sand (SP).

3. PAST PERFORMANCE.

Three problem areas were identified during the phase one study. These are Sites 150-8, 150-9, and 150-11. Seepage was the identified problem at Sites 150-8 and 150-9 (Figure 25A). A serious boil reportedly occurred in a drainage ditch at Site 150-8 in 1986. At Site 150-11, waterside slumping was reported. During discussions with the president of R.D. 150 during the phase three inspection, it was learned that this was a short reach that was repaired by the District using cobble slope protection.

4. CONCLUSIONS AND RECOMMENDATIONS.

The two primary sites of concern are Sites 150-8 and 150-9. An irrigation ditch with standing water exists at both sites (Figure 25A). Levee stability is considered adequate.

However, based on past performance including sand boils in the irrigation ditch at Site 150-8 (500 feet) and similar conditions at Site 150-9 (1100 feet), it is recommended that the irrigation ditch be replaced with a drainage collector system. This would require installation of a drainage collector system at each site (Alternative H).

#### O. ELK SLOUGH - RIGHT BANK LEVEE (R.D. 999)

The right bank levee of Elk Slough is approximately 9.66 miles in length. It extends from the confluence of the Sacramento River at the upstream end to the confluence of Sutter Slough at the downstream end (Figure 3).

##### 1. EXPLORATIONS.

The only explorations performed along this reach were 2F-91-32 and 32A drilled during the phase three investigations. These borings were drilled just upstream of two erosion identified problem areas, Sites 999-4 and 999-5.

##### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 26. Based on the limited exploration data in this reach, the levee and foundation soils are primarily lean clay (CL) and fat clay (CH) with sand. Cross section survey information was limited in this reach. However, based on the phase three field inspection, the following generalizations can be made. The levee height varies from approximately 10 to 15 feet. Upstream of Netherlands Road, or about two-thirds of the reach, the levee is gravel surfaced and relatively wide, varying from about 30 to 40 feet. The landside slope is grassy and generally flat at about 1V on 3H to 5H. Downstream of Netherlands Road, the levee is a two lane paved road, with narrow shoulders. The levee slopes are typically 1V on 2H waterside and 1V on 2H to 3H on the landside. The levee slopes, particularly the waterside slope, are heavily vegetated with cottonwood trees, blackberry bushes and various other types of vegetation. Although, not particularly ideal for inspection purposes, there were no indications of slope instability, except for erosion near the water surface which is discussed further in the following paragraph.

##### 3. PAST PERFORMANCE.

The only problems identified in this reach during the phase one investigation were Sites 999-4 and 999-5. These were sites that were identified as having waterside scarps caused by erosion and slippage. Field observations made during the phase three inspection revealed that overall the levee in this reach is in good condition. As mentioned in the above paragraph, the lower portion of the waterside slope has eroded which has led to progressive failure of lower portion of the slope. The phase three inspection found this to be the case at Sites 999-4 and 999-5. Site 999-4 is only about 15 feet wide. However, Site 999-5 (Photos 16 and 17) is approximately 500 feet wide. It was very difficult to access the actual limits of Site 999-5 due to the heavy vegetation on the waterside slope. However, a vertical scarp in the lower portion of the waterside slope was evident. In addition, stress cracks just above the vertical scarp were visible in portions of this area.

##### 4. CONCLUSIONS AND RECOMMENDATIONS.

The erosional scarp at Site 999-4 is relatively small. According to the general manager for R.D. 999, the District has plans to place concrete rubble at the toe of the slough and

backfill above the rubble with earth fill. The problem at site 999-5 is more serious. This reach is wider and signs of advancing damage into the levee section are apparent. According to the general manager, environmental restrictions, have prevented the District from placing riprap in the slough against the levee. If measures such as placing rock or stonefill in the slough against the deteriorating slope are not taken, the damage in this area will worsen and ultimately may result in a possible slope failure involving the levee crown. It is recommended that stonefill and riprap be placed at the toe of the levee in this reach to halt the progressive sloughing of the waterside slope.

**P. SUTTER SLOUGH - LEFT BANK LEVEE (R.D. 349)**

The left bank levee of Sutter Slough is approximately 6.55 miles in length. It begins at the confluence of the Sacramento River at the upstream end and terminates at the downstream end at the confluence of Steamboat Slough (Figure 4).

**1. EXPLORATIONS.**

There are a total of five explorations for this reach. Boring 2F-56-3 was drilled at the downstream limit of this reach to evaluate the seepage and the boil situation at the tip of Sutter Island. This situation is discussed in detail in paragraph K. Borings 2F-64-3 and 4 were drilled in 1964 for bank protection investigations. Borings 2F-91-29 and 29A were drilled during the phase three study.

**2. LEVEE AND FOUNDATION CONDITIONS.**

The levee and foundation profile for this reach are shown on Figure 27. Based on surveyed cross sections from the confluence of Steamboat Slough to Miner Slough, the levee height varies from 16 to 25 feet. The landside slope varies from 1V on 1.9H to 2.6H. The waterside slope varies from 1V on 2.2H to 4H.

**3. PAST PERFORMANCE.**

Except for the sand boil problem at the tip of Sutter Island, discussed in detail in paragraph K, and some past bank erosion in previous years, no other problems were reported along this reach.

**4. CONCLUSIONS AND RECOMMENDATIONS.**

The left bank levee of Sutter Slough has performed well and there are no recommendations for levee modifications along this reach.

**Q. MINER SLOUGH - LEFT BANK LEVEE (R.D. 501)**

The left bank levee of Miner Slough extends for a total of approximately 7.8 miles from the confluence of Sutter Slough at the upstream end to Cache Slough at the downstream end (Figure 4).

**1. EXPLORATIONS.**

Six borings were drilled during this study for this reach. They include 2F-90-24 and 25 drilled during the phase two study and borings 2F-91-25, 25A, 26, and 26A drilled during the phase three study. Borings through the levee crown ranged from 40 to 56.5 feet in depth and

the levee landside toe borings were drilled from 20 to 27.5 feet deep.

## 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 28. Based on several survey cross sections along this reach in 1991, the levee height varies from 16 to 25 feet and averages 20 feet. The crown is a paved two lane road and the levee width varies from 20 to 38 feet and averages 31 feet. The landside slope varies from 1V on 1.6H to 3.3H and averages 1V on 2.3H. The waterside slope varies from 1V on 1.5H to 3.2H and averages 1V on 2.1H. Based on exploration data, the levee consists of clayey sand and silt at the upper end of Miner Slough and near the lower end consists of loose poorly graded fine to medium sand. The foundation soils consist predominantly of fine grained silty sand (SM) and clay (CL) with organics. Standard penetration blow count data indicate the consistency of the foundation silt and clay is soft.

## 3. PAST PERFORMANCE.

Three problem areas were identified along Miner Slough during the phase three study. The first is 501-3 (Photo 18), where heavy seepage was reported to be a problem over a 1.2 mile reach with localized waterside slumping. The second seepage area reach was identified as 501-4, where seepage is reported over a 1 mile reach. The final reach, 501-5 (Photo 19), is a 0.5 mile area where seepage was reported as well as small slumps in the waterside bank.

## 4. CONCLUSIONS AND RECOMMENDATIONS.

Seepage and stability analyses were performed at Site 501-3 in the phase two study. The result of that analysis was a minimum factor of safety of 1.0. The minimum factor of safety from the seepage analysis was calculated to be 0.6. A reanalysis of slope stability in the phase three study resulted in a factor of safety of 1.43 (Figure 28A). The design freeboard used in the phase two analysis was 3 feet. During the phase three study it was determined that the actual freeboard is approximately 8 feet (Figure 28). This correction, in addition to using effective strength values rather than total strength values, which are considered overly conservative, yielded a minimum factor of safety of 1.43. Seepage was also reanalyzed. Using the corrected flood level and considering seepage losses through the levee foundation, the seepage exit gradient is on the order of 0.4 to 0.5. This translates to a factor of safety of greater than 2. Therefore, it is concluded that no levee modifications are necessary in this reach. Sites 501-4 and 501-5 are considered no worse and probably better than Site 501-3. The main concern is continual loss of the waterside slope and levee foundation in this area due to erosion. This contributes to increased seepage by reducing the length of the seepage path and thereby increasing seepage exit energy on the landside of the levee. Ultimately, this can cause what is presently considered a nuisance seepage condition during high water in some areas to a more serious foundation piping problem. Therefore, it is recommended that the local reclamation district place a higher priority on bank protection along Miner Slough. When localized erosion of the bank does occur, it should not be allowed to go unprotected for any extended length of time. Bank protection should be placed with minimal delay.

#### R. CACHE SLOUGH - LEFT BANK LEVEE (R.D. 501)

This reach of levee is approximately 3.6 miles in length extending from the confluence of Cache Slough and Miner Slough at the upstream end to the confluence of Cache Slough and Steamboat Slough at the downstream end (Figure 4).

##### 1. EXPLORATIONS.

Very little exploration data prior to the phase two explorations is available. Six auger borings (2F-90-19, 19A, 20, 21, 22, and 23 were drilled during the phase two explorations. Borings from the levee crown extended to a maximum depth of 52.5 feet and the toe borings were drilled to a depth of 27.5 feet. No additional explorations were performed in this reach during the 1991 study.

##### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 29. Twelve surveyed cross sections along this reach indicate the levee height varies from 16 to 23 feet and averages 18 feet. The crown is a paved two lane road and the levee width varies from 25 to 48 feet and averages 33 feet. The landside slope ranges from 1V on 1.6H to 3.6H and averages 1V on 2.3H. The waterside slope varies from 1V on 1.5H to 5.8H and averages 1V on 2.8H. Based on available explorations, the levee soils range from clean, mostly loose, fine grained sand (SP) to medium stiff silt (ML). The upper few feet of the foundation at boring 2F-90-20 beneath the levee, consists of clean sand deposits. This is likely the sand material that was dredged from Cache Slough to repair the 1904 levee break at this location. Portions of the foundation south of Elkhorn Slough consist of soft deposits of organic clay and peat soils. North of Elkhorn Slough, the levee consists of silt (ML) and fine to medium sand (SP). The foundation soils in this reach consist predominantly of silt (ML) with some isolated deposits of high plasticity clay (CH).

##### 3. PAST PERFORMANCE.

During the phase one investigation, seepage and bank erosion and slumping was reported as the primary problems. In fact, this entire reach was identified as problem Site 501-1 in the phase two study. Corps records verify that erosion and slips of the waterside bank and levee have been an ongoing problem in this reach as long ago as 1955. Bank protection has been placed over this entire reach at various times in the past 35 years. A levee failure occurred in 1904 where shown on the location map and Photo 20. A representative of R.D. 501 reported that generalized seepage has occurred in several areas in recent years. In addition, it was reported that during the 1986 flood, a boil occurred low on the levee slope in the general area of the 1904 levee break.

##### 4. CONCLUSIONS AND RECOMMENDATIONS.

Although seepage is a general problem along this reach during high water, the primary concern is continual loss of the waterside levee slope. High flows in the Yolo Bypass can directly impinge on the levee in this reach. Continual erosion also occurs as a result of waves generated from wind and large vessels in the ship channel. Undercutting of the bank below the water surface may also be occurring along this reach. If so, this could exacerbate this problem. As more and more of the waterside slope and foundation of the levee is lost, there is an increased potential for seepage to develop from what is presently considered

nuisance seepage to problem seepage. It is judged that the seepage that presently occurs during high water stages does not warrant seepage control measures at this time. However, continual loss of the waterside slope and foundation due to erosion may ultimately decrease the integrity of the levee through foundation piping or slope instability. Therefore, as concluded with left bank of Miner Slough, it is recommended that the local reclamation district place a higher priority on bank protection along this reach. When localized erosion of the bank does occur, it should be repaired with bank protection with minimal delay.

The site of the 1904 levee break is also of concern (Site 501-1A). The boil that occurred on the landside slope during the 1986 flood indicates a potentially unstable condition. As indicated on the levee profile, the material used to reconstruct the levee at this location following the 1904 levee break is clean sand (SP) believed to have been dredged from Cache Slough. In order to improve the overall stability at this location, a landside seepage/stability berm is recommended in a 1200-foot reach centered on the 1904 break. The berm will provide seepage control and improve overall stability.

#### S. CACHE AND HAAS SLOUGH - LEFT BANK LEVEE (R.D. 2098)

This levee reach includes approximately 4.25 miles along the left bank levee of Cache Slough (Figure 4). It extends from the west end of the new cross levee near the confluence of Cache Slough upstream to the point where the levee turns toward a northerly direction.

##### 1. EXPLORATIONS.

A total of eight exploratory drill holes (5F-62-7, -8 and 2F-91-11 through -15) were drilled in this reach. All but one (2F-91-11A) were drilled from the top of the levee. Boring 2F-91-11A was drilled to a depth of 20 feet and the levee crown borings varied in depth from 35 to 45 feet deep.

##### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 30. The levee and foundation soils are fairly consistent throughout this reach. The levee soils consist predominantly of stiff fat clay (CH) and lean clay (CL) with some intermixing of peat deposits. The foundation soils are similar, although firm rather than stiff and with thicker deposits of fat clay (CH) with intermixing of peat deposits and organic clay. Surveyed cross sections were taken at approximately 2000-foot intervals in this reach. The levee height varies from about 15 to 21 feet and the levee crown which is unpaved varies in width from approximately 17 to 22 feet. The landside slope is relatively uniform, varying from about 1V on 2.5H to 2.6H. The waterside slope is also relatively uniform, varying from 1V on 2.9H to 3.2H. Unequal settlement has resulted in an undulating road surface with occasional potholes. The levee slopes, particularly the waterside slope are heavily vegetated with grasses, small brush and trees which obscure visibility for inspection purposes.

##### 3. PAST PERFORMANCE.

Problems reported in this reach include cracking of the levee crown, levee slumping and erosion of both the waterside and landside slopes. Site 2098-8 was identified in the phase one study as two waterside slope failures with head scarps which have progressed to within 3 feet of the levee road surface. This site was inspected during the phase three inspection (Photos 21 and 22). At least three erosional scarps varying from 150 to 200 feet wide were

apparent during the inspection. The scarps are serious and are discussed further in the following paragraph. Site 2098-9 was identified as a 350-foot reach where previous slumping of the levee was repaired by raising and riprap was placed in a wave cut bank. There was no obvious indication of stress or damage in this levee section during the phase three inspection. Site 2098-10 was identified as a reach approximately 2500 feet in length which has been rebuilt due to chronic slumping. Two large landside slumps were noted in this 2500-foot section during the phase three inspection. The levee road has been diverted slightly around the larger of the two slumps. The lower portion of the landside slope has had significant erosion along this entire reach (Photo 23). This has resulted in a vertical scarp of around 5 feet or more and also likely contributed to the two slope failures. Site 2098-11 is reported to be a short reach in the levee at the Sycamore Slough closure where slumping has repeatedly occurred in the past requiring periodic repairs. This is evidenced by the flatter than normal levee slopes at this location. However, there are no indications of recent unstable conditions.

#### 4. CONCLUSIONS AND RECOMMENDATIONS.

It is recommended that the erosional scarps at Site 2098-8 be repaired. If left unrepaired, significant levee damage or failure may ultimately occur at this location. This will require stonefill and rock slope protection to prevent future erosion. There were no obvious indications of needed reconstruction at Sites 2098-9 and 2098-11. However, extensive landside slope repairs are needed for the 2500-foot reach identified as Site 2098-10. This will require reconstruction of the slope, using stonefill below the water surface in the adjacent slough and earthfill or stonefill above the water surface. In addition, riprap should be used on the lower portion of this slope to prevent future damage. Levee landside slope cracking (Site 2098-10A) was also noticed along an approximately 400-foot section of levee just upstream of this area (Photo 24). The adjacent irrigation ditch, which was being cleaned at the time of the phase three inspection, has resulted in loss of supporting foundation. This apparently has contributed to instability. It is recommended that the ditch be drained and backfilled. The ditch can either be rerouted so that it is at least 75 feet from the levee toe, or a large pipe (CMP) could be installed prior to backfilling the ditch.

#### T. YOLO BYPASS - RIGHT BANK LEVEE (R.D. 2068, R.D. 2098, and R.D. 2060)

This reach includes a total of approximately 9.5 miles of the right bank of Yolo Bypass. R.D. 2068 maintains the upstream 4.3 miles, R.D. 2098 maintains the next 4.3 miles, and R.D. 2060 maintains the lower 1 mile section across Cache Slough (Figures 3 and 4).

##### 1. EXPLORATIONS.

Eight exploratory borings (2F-91-9, 9A, 10, 10A, 18, 18A, 19, and 19A) were performed during the phase three explorations. Borings drilled through the top of the levee extended to 40 feet and toe borings were drilled to a depth of 20 feet.

##### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 31. The levee and foundation soils along this entire reach consist of clay (CH) and organic clay (OH). Standard penetration blow count data indicate the levee soils are soft to firm, while the underlying foundation is firm. Toe borings indicate the foundation material not immediately beneath the

levee is weaker, varying in consistency of very soft to firm.

### 3. PAST PERFORMANCE.

The levee along this reach has experienced chronic instability in past years. Cracks in the pavement and the undulating levee surface of this entire reach are typical of levees which are constructed on soft clay or peaty soils. At the downstream end of Site 2068-1 a significant landside slope failure occurred in 1974. This was repaired by the Corps of Engineers and according to representatives of the local reclamation district, this same location has been repaired more than once by their own forces. Except for this one location, there has not been any major failures. The biggest concern in this reach is the potential for decreasing levee stability resulting from the continual erosion and sloughing of both the landside and waterside berms. The material used to construct this reach of levee was borrowed on the landside, very close to the levee. The once existing landside berm between the borrow pit and the levee is gradually eroding away (Photos 25 and 26). Presently there are vertical scarps and signs of progressive slumping landside berm which is typically from 0 to 10 feet wide. Site 2060-2 along Wright Cut was identified as a 500-foot reach where the levee crown was reported as being low and where seepage occurred in 1986. The seepage was primarily noted in the field beyond the levee. Since that occurrence no seepage has been reported. Extensive landside erosional gulling (Photo 27) was found during the phase three site inspection. Although not a serious threat to levee stability, this will require maintenance type repairs by the local reclamation district. The levee along the R.D. 2098 portion of this area is generally considered in fair condition. Instances of seepage and isolated landside slope failures have been reported. Some erosion on the waterside bank also exists in this reach. Indications of historical subsidence reported at Site 2098-3 was not apparent during the phase three inspection. No remnant indications of seepage were apparent at Site 2098-4, where seepage was a reported problem.

### 4. CONCLUSIONS AND RECOMMENDATIONS.

Although there have not been a significant number of slope failures in this reach to date, there is evidence that stability is borderline. Longitudinal cracks, undulations in the asphalt road surface, and cracks in the lower landside slope above vertically eroded scarps are some of the signs of instability. Along a portion of the R.D. 2068 levee, the landside and waterside berms are actively eroding and sloughing in several locations (Site 2068-1). In some areas, the berm is nonexistent and the sloughing has worked into the levee section. Where this has occurred, there are signs of cracks in the levee slope above the sloughing berm. In order to improve the overall stability of the levee, the following recommendations are made. A berm of at least 10 feet wide should be reconstructed where it is less than 10 feet and stone protection should be used to prevent future berm erosion. The only recommendation for Site 2068-2, located just south of Site 2068-1, is to prevent further loss of the existing berm which is currently 10 to 20 feet wide. This should be accomplished by placing slope protection on the waterside bank. The reach along R.D. 2098 has had some bank erosion. However, bank protection has been added by the Corps in previous years and appears to be in relatively good condition. Some other problems reported along this reach appear to be isolated and do not reflect an overall problem with the R.D. 2098 section of levee along Yolo Bypass. However, future bank protection will be required on an as needed basis. During the phase three inspection, Site 2060-2 appeared to have been recently raised. The levee slopes were uniform and no indication of seepage was detected. No repairs are recommended for this site.

#### U. LINDSEY SLOUGH - LEFT BANK LEVEE (R.D. 2060)

The left bank levee of Lindsey Slough extends for a distance of 5 miles from Yolo Bypass to Hastings Cut (Figure 4).

##### 1. EXPLORATIONS.

The only explorations conducted in this reach were borings 2F-91-17 and 17A located just upstream of the Hastings Tract bridge. These borings were drilled to depths of 40 feet from the top of the levee and 20 feet at the levee toe.

##### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 32. Levee cross section data in this reach indicates that the levee height typically varies from about 13 to 20 feet and averages about 17 feet. The width of the gravel surfaced levee crown varies from about 15 to 20 feet. Both the landside and waterside levee slopes are relatively flat, ranging from approximately 1V on 2.8H to 4.0H (average 3.6H) on the landside, and from 1V to 3.0H to 6.6H (average 4.6H) on the waterside. Based on the minimal exploration data, the levee material consists of firm to stiff fat clay (CH) and the foundation soil consists of very soft to soft organic clay (OH). Standard penetration data indicate the foundation soils directly beneath the levee are firm, likely due to consolidation.

##### 3. PAST PERFORMANCE.

During the phase three field inspection, it was observed that the levees in this reach are in very good condition. There were no signs of sloughing, cracking or slope instability. However, there were several locations along this reach where erosion and sloughing of the waterside bank has resulted in vertical scarps. Several of the scarps are on the order of 20 to 30 feet wide and 5 or more feet vertical. The waterside berm along this reach is generally less than about 20 feet wide in most areas. It was noted that several areas have been treated with rock revetment in the past and appear to be stable. The only problem site was that identified in the phase one study was Site 2060-1 where seepage and bank erosion was the reported problem. During the phase three inspection, levee in this location showed no signs of seepage or instability. However, just upstream of this site, approximately 300 feet from the bridge, is a 30-foot wide erosional scarp (Photo 26). This is similar to previous scarps on the bank which have been repaired by the local reclamation district.

##### 4. CONCLUSIONS AND RECOMMENDATIONS.

Several isolated locations along the waterside bank have sloughed and or eroded along this reach. These areas are in need of rock revetment. However, there were no other signs of levee instability or stress. There are no recommendations for levee reconstruction in this reach.

#### V. LINDSEY SLOUGH - RIGHT BANK LEVEE (R.D. 536)

The right bank levee of Lindsey Slough is approximately 5.66 miles in length. This section of levee protects Reclamation District 536 from flooding (Figure 4).

##### 1. EXPLORATIONS.

Only two exploratory borings were completed along this reach. These were borings 2F-91-16 and -16A. These were drilled just upstream of Hastings Tract bridge in the only location that had been reported as having past problems (Site 536-1).

##### 2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 33. The levee is typically from 15 to 20 feet in height in this reach. The levee crown varies from approximately 20 to 30 feet wide. The levee side slopes are relatively flat. The landside slope varies from approximately 1V on 2.6H to 3.5H (average 2.9H). The waterside slope varies from 1V on 2.6H to 3.6H (average 3.2H). The levee is gravel surfaced for most of this reach and portions of the waterside slope are densely vegetated with brush and trees. Borings 2F-91-16 and -16A indicate the levee soils consist of firm to stiff fat clay (CH) with traces of organics. The foundation soils are similar with traces of peat deposits and somewhat softer with a soft to firm consistency.

##### 3. PAST PERFORMANCE.

The only location identified as having past problems is an 800-foot reach of levee just upstream of the Hastings Tract bridge (Site 536-1). It was reported that the levee crown has subsided in the past and erosion was reported to have caused undercutting and slumping of the waterside bank. A review of Corps of Engineer files indicate another problem site was reported in October 1973, about 350 to 400 feet downstream of the Hastings Tract bridge. It was reported that the levee crown for a distance of about 210 feet wide on the levee crown and 400 feet long along the landside toe "humped" upward. It was reported that the reclamation district was planning on placing dredged material about 4 feet high along the landside toe in this location. Although not known for sure, it is presumed that this work was accomplished and no subsequent problems occurred.

##### 4. CONCLUSIONS AND RECOMMENDATIONS.

This entire reach of levee is generally in good condition. Although Site 536-1 has been reported to have experienced past slumping, it presently appears to be stable. The foundation clays, at least at this site are relatively soft and low in shear strength. However, the generally flat levee slopes in this area and general appearance indicate a stable condition. If any future settlement or slumping does develop, it is not viewed as a threat to complete levee failure. Therefore, there is no recommendation to make repairs to this section of levee.

#### W. HAAS SLOUGH - RIGHT BANK LEVEE (R.D. 2104)

The right bank levee of Hass Slough along this reach is approximately 3.5 miles in length, and protects Peters Pocket (R.D. 2104) from flooding during flood stages in the Yolo Bypass (Figure 4).

1. EXPLORATIONS.

The only explorations conducted for this study along this reach are borings 2F-91-8, and -8A) drilled to depths of 40 feet and 20 feet respectively.

2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 34. The foundation soils consist primarily of very soft to soft clay (CL) and (CH). The levee side slopes are typically 1V on 2H landside and 1V on 3H on the waterside with a 12-foot wide crown. The levee surface is unpaved and as a result during wet soil conditions, these levees are not trafficable. As a result, wheel ruts were left in portions of the levee crown during the phase three inspection. The Corps' Operation Branch personnel reported this condition to the landowners as the levee surface in a short reach will need to be regraded.

3. PAST PERFORMANCE.

One past problem area was reported in the phase one study. This was Site 2104-6. It was reported that historical slumping has been a problem in this area. It was reported that repairs were necessary during the 1950's and again in 1986. However, there were no indications of levee instability detected during the phase three field inspection. The levee slopes appeared to be very uniform and well groomed.

4. CONCLUSIONS AND RECOMMENDATIONS.

This levee reach appears to be in a relatively stable condition with no major structural problems. Therefore, there are no recommendations for reconstruction of any portion of this reach.

X. CACHE SLOUGH - RIGHT BANK LEVEE (R.D. 2060)  
AND LEFT BANK LEVEE (R.D. 2104)

This reach includes approximately 4 miles of levee along the right bank levee of Cache Slough (R.D. 536, Egbert Tract) and 2.5 miles of levee along the left bank of Cache Slough (R.D. 2104, Peters Pocket) (Figure 4).

1. EXPLORATIONS.

A total of eight exploratory drill holes were performed along this reach during the phase three study. These included borings 2F-91-20 and -20A on the right bank of Cache Slough and 2F-91-5, 5A, 6, 6A, 7, and 7A along the left bank levee of Cache Slough. All four levee borings were drilled to a depth of 40 feet and the landside toe borings were drilled to depths of 20 feet.

2. LEVEE AND FOUNDATION CONDITIONS.

The levee and foundation profile for this reach are shown on Figure 35. The levee materials consist predominantly of clay (CL and CH) with limited amounts of fine sand. The levee materials are firm to stiff, while the consistency of the foundation clay is from very soft to firm. The levee crown throughout this reach varies in width from about 13 to 19 feet and averages around 15 feet. The landside levee slope is notably flatter on the right bank levee (R.D. 2060), typically about 1V on 4H, while on the left bank (R.D. 2104) the landside slope is generally around 1V on 2.5H. The waterside slope on the right bank levee is also notably

flatter at 1V on 4H compared to about 1V on 3H on the left bank.

3. PAST PERFORMANCE.

Problems along this reach have been minimal. Only one problem site was identified in the phase one study. This was Site 2060-3. Minor past seepage was identified in this location. In general, the levees have performed well during high water. There have been no boils or slumps reported. During the phase three inspection, a levee slump, Site 2060-3A, on the waterside slope was discovered approximately 2000 feet downstream of Site 2060-3. The slump (Photo 27) is approximately 100 feet in length, but does not extend into the levee crown. However, if not repaired, the slump could worsen and threaten the entire levee section. Some erosion of the waterside bank was also discovered during the phase three inspection (Photo 28). Although not extremely significant, it and any other future erosion and/or bank sloughing should be provided with bank protection by the local reclamation district.

4. CONCLUSIONS AND RECOMMENDATIONS.

Both the right and left bank levees in this reach are in good condition. The only site noted where reconstruction is necessary is at the levee slump at Site 2060-3A, which is located just downstream of Site 2060-3. This site will require excavation and recompaction of the levee material.

## Y. REFERENCES.

1. Harlan Tait Associates, "Report on Recommendations for Explorations, Further Study, and Laboratory Testing for the Preliminary Assessment of the Levees of the Lower Sacramento River Area, Phase IV, Sacramento River Flood Control System Evaluation, "April 25, 1990.

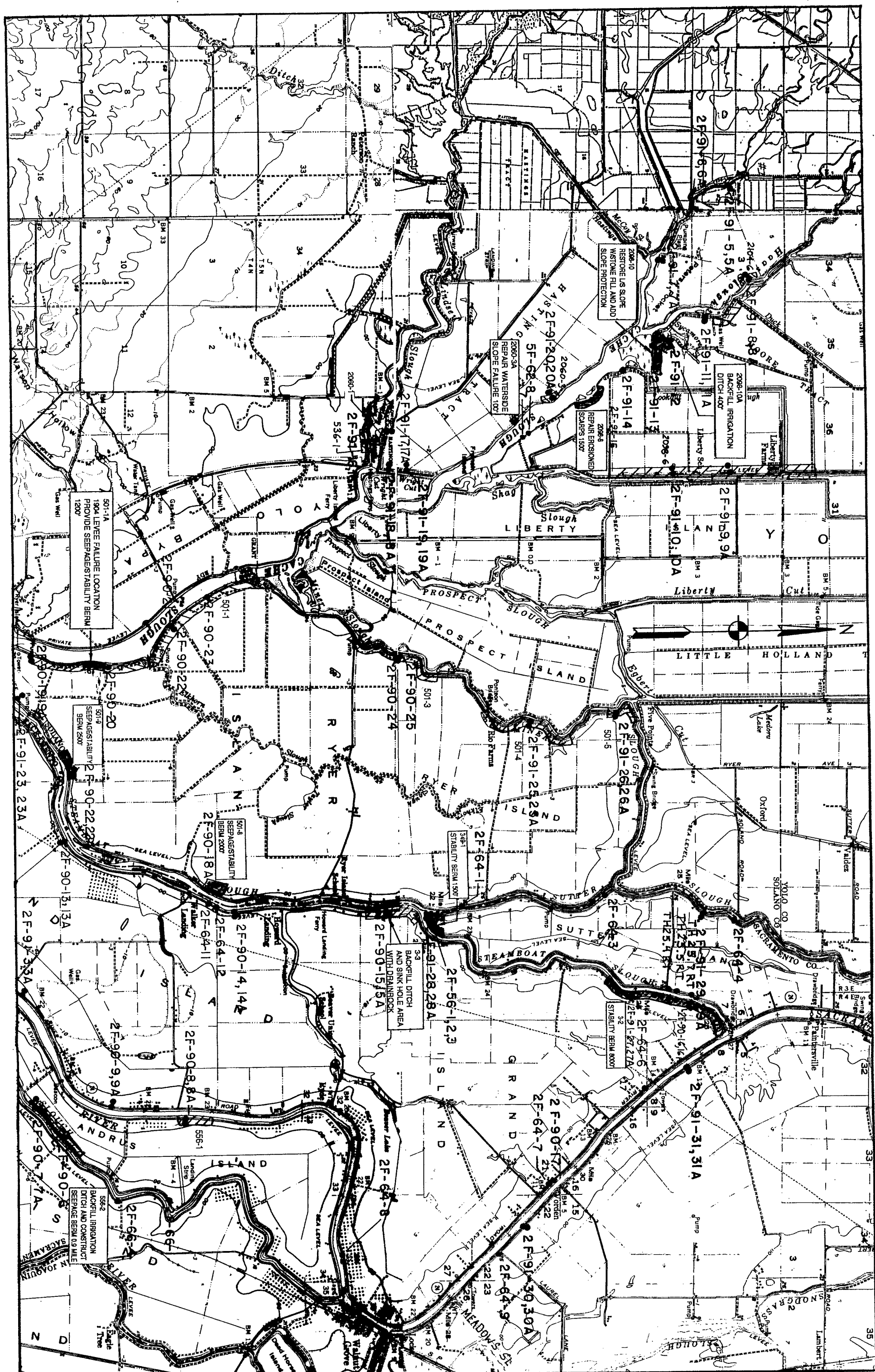
2. Harlan Tait Associates, "Report on the Preliminary Geotechnical Assessment of the Levees in the Southern Portion of the Lower Sacramento River Area, Phase IV, Sacramento River Flood Control System Evaluation," February 12, 1991.

3. U.S. Army Corps of Engineers, South Pacific Division Laboratory, "Report of Soil Tests, Sacramento River Flood Control System Evaluation, Lower Sacramento Area, Phase IV," September 1990.

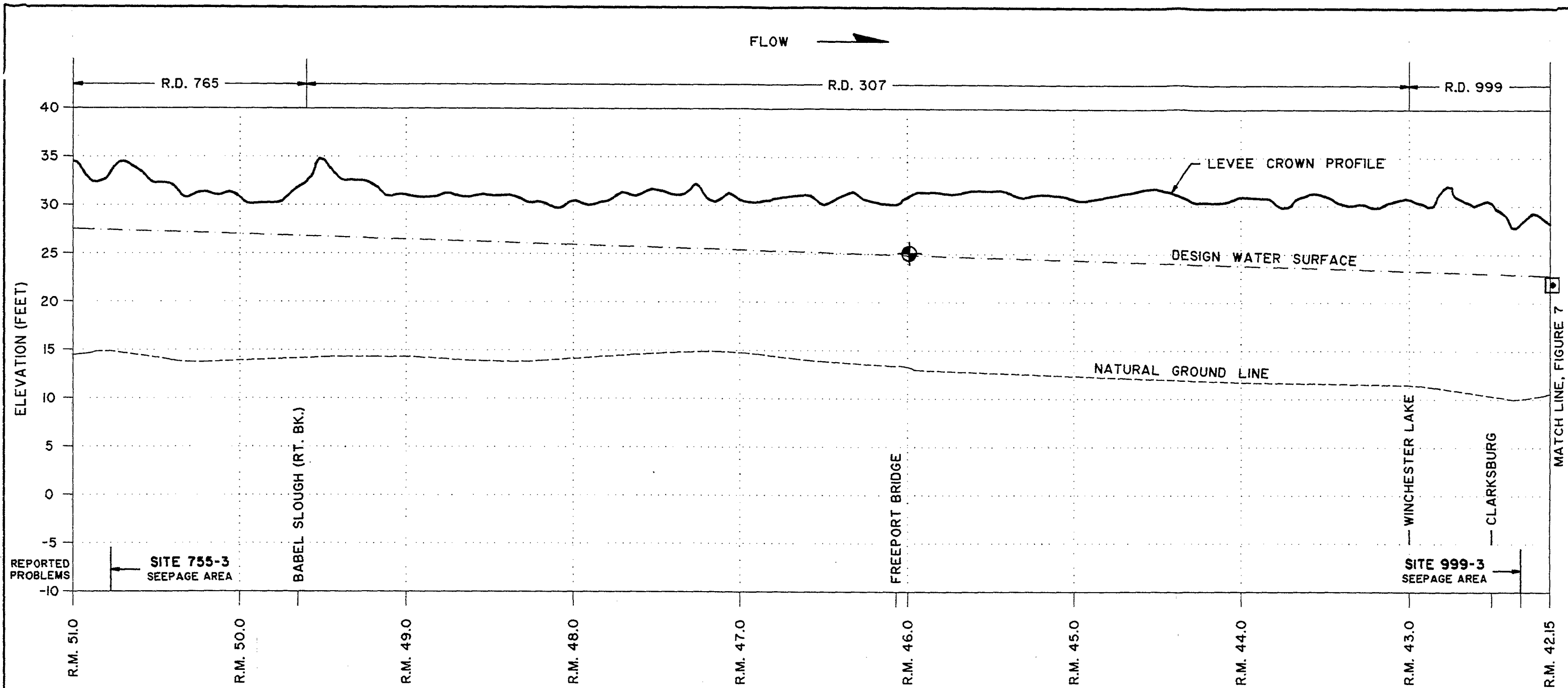
4. U.S. Army Corps of Engineers, South Pacific Division Laboratory, "Report of Soil Tests, Sacramento River Flood Control System Evaluation, Lower Sacramento Area, Phase IV," November 1991.









**NOTES:**

- WHERE LABORATORY CLASSIFICATION DATA IS AVAILABLE, SOIL LEGEND GENERALLY CONFORMS TO ASTM D2487 EXCEPT THAT NO DISTINCTION IS MADE BETWEEN SILT AND SILT WITH SAND OR BETWEEN CLAY AND CLAY WITH SAND. FOR THE PURPOSE OF THIS STUDY, ALL SAND DEPOSITS WITH LESS THAN 12% FINES CONTENT ARE INDICATED AS CLEAN (RELATIVELY HIGH PERMEABILITY).
- UNITS OF HORIZONTAL AXIS ARE IN FEET CORRESPONDING TO STATIONING BY DWR (DWR, 1990) OR BY RIVER OR CHANNEL MILES. THE CROWN ELEVATION IS BASED ON SURVEYS CONDUCTED BETWEEN MAY AND AUGUST 1990 BY THE CALIFORNIA DWR IN COOPERATION WITH THE CORPS OF ENGINEERS. IN SOME REACHES ADDITIONAL SURVEYING WAS CONTRACTED OUT BY THE CORPS OF ENGINEERS. THE DESIGN WATER SURFACE PROFILE AND NATURAL GROUND ELEVATION LINE ARE BASED ON "LEVEE CHANNEL PROFILES, CORPS OF ENGINEERS," MARCH 1957.

SILT (>70% FINES)  
 SILTY SAND OR SANDY SILT (12%-70% FINES)  
 CLAY (>70% FINES)  
 CLAYEY SAND OR SANDY CLAY (12%-70% FINES)  
 SAND (<12% FINES)  
 OH

**LEGEND**

CLAY (HIGH PLASTICITY, CH)  
 PEAT  
 PERCENTAGE OF FINES (MINUS 200 SIEVE SIZE) PER LABORATORY TESTING  
 FEBRUARY 1986 HIGH WATER MARKS  
 SURVEYED  
 STAGE RECORDERS

SCALE: 1" = 3000'

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**LEVEE PROFILES**  
**SACRAMENTO RIVER**  
**RIGHT BANK - R.M. 42.15 TO 51.0**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS  
DRAWN BY: R. IWASA

FEBRUARY 1993

MATCH LINE, FIGURE 7

C-103568

FIGURE 6

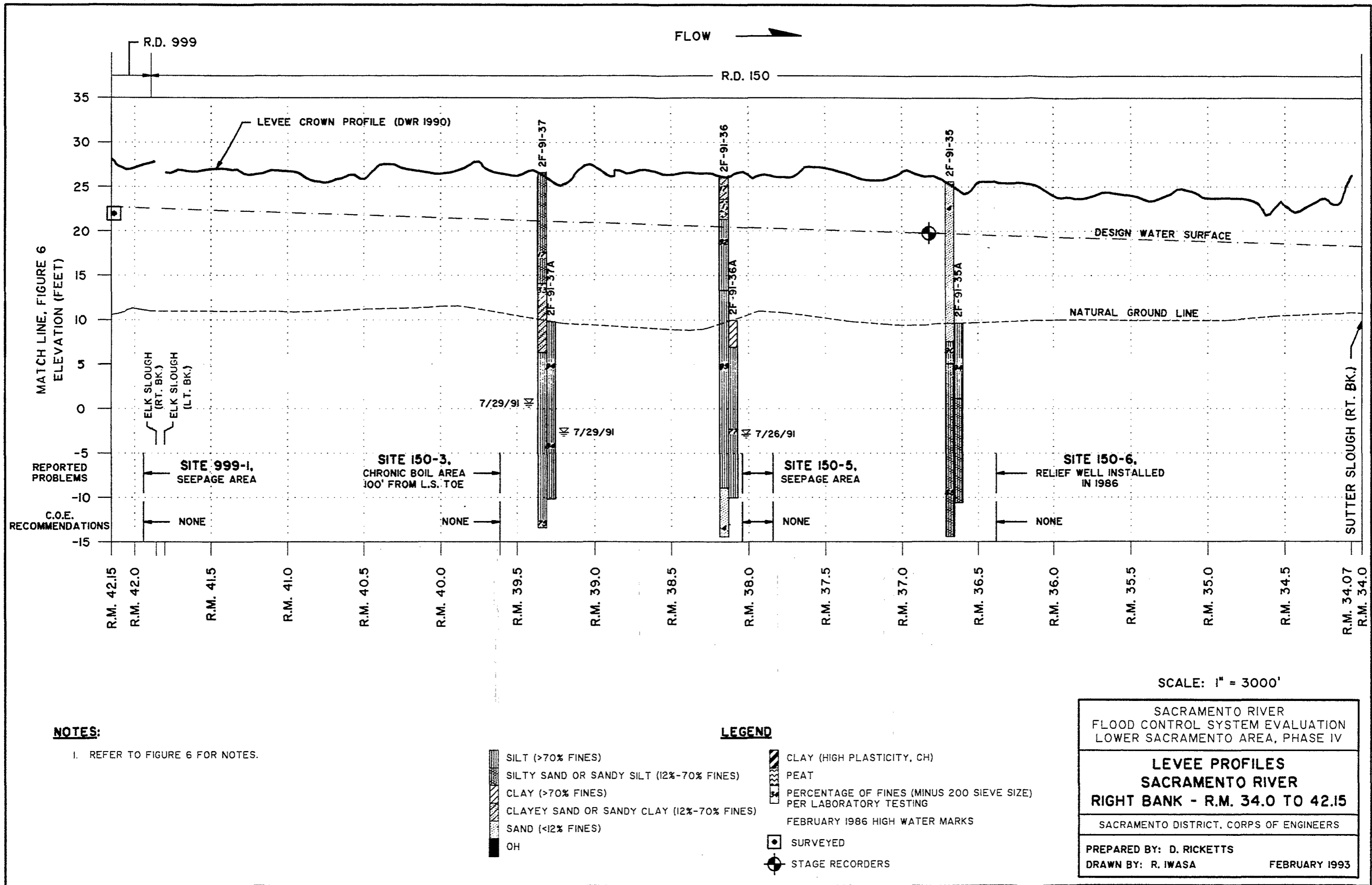
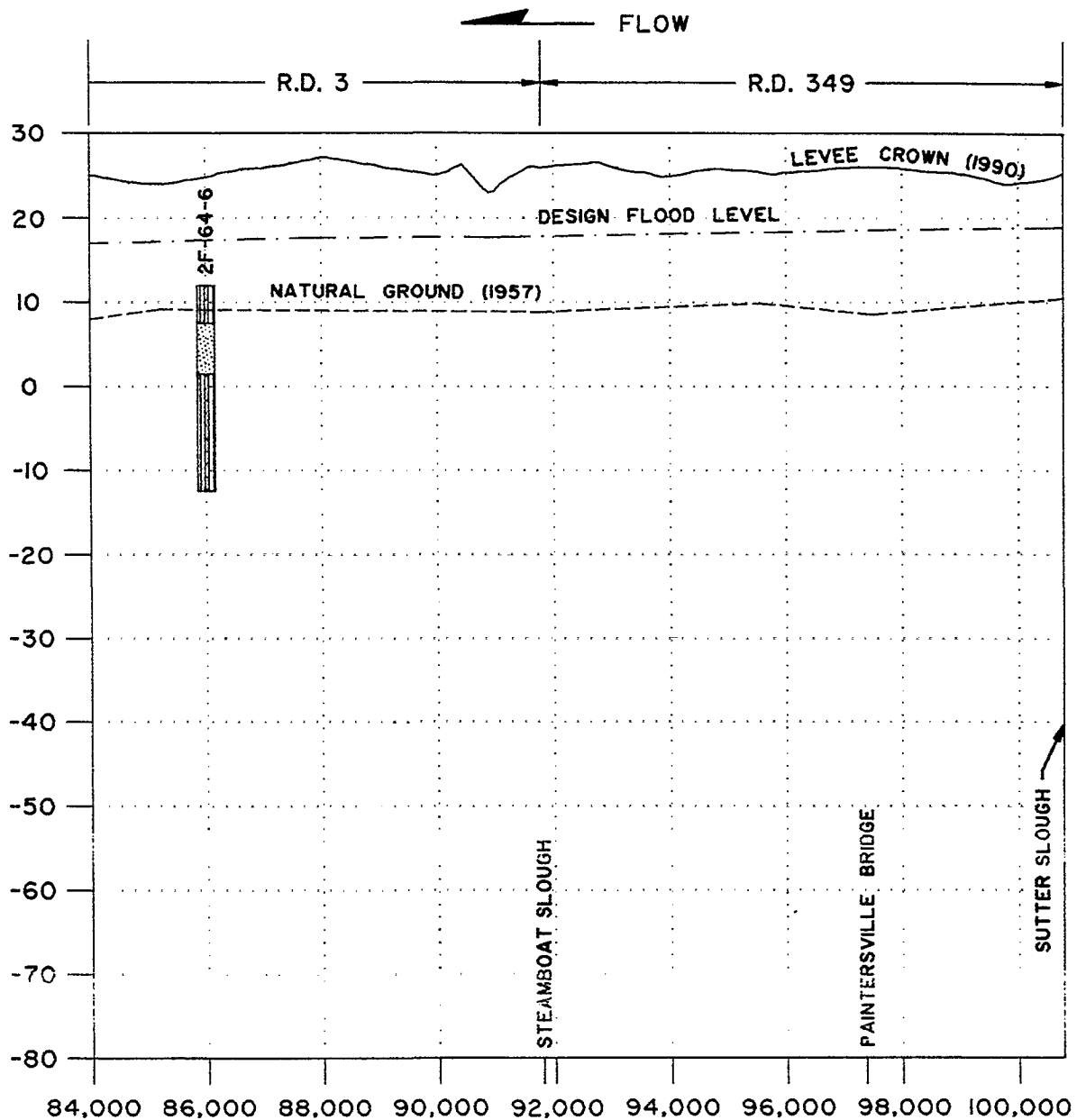


FIGURE 7

MATCH LINE, FIGURE 9  
ELEVATION (FEET)



SCALE: 1" = 3000'

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**LEVEE PROFILES  
SACRAMENTO RIVER  
RIGHT BANK LEVEE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

DRAWN BY: R. IWASA

FEBRUARY 1993

**NOTE:**

I. REFER TO FIGURE 6 FOR NOTES AND LEGEND.

GEO TECH - SOILS\R.IWASA\LSAC-F08.DWG\02-11-93

FIGURE 8

C - 1 0 3 5 7 0

C-103570

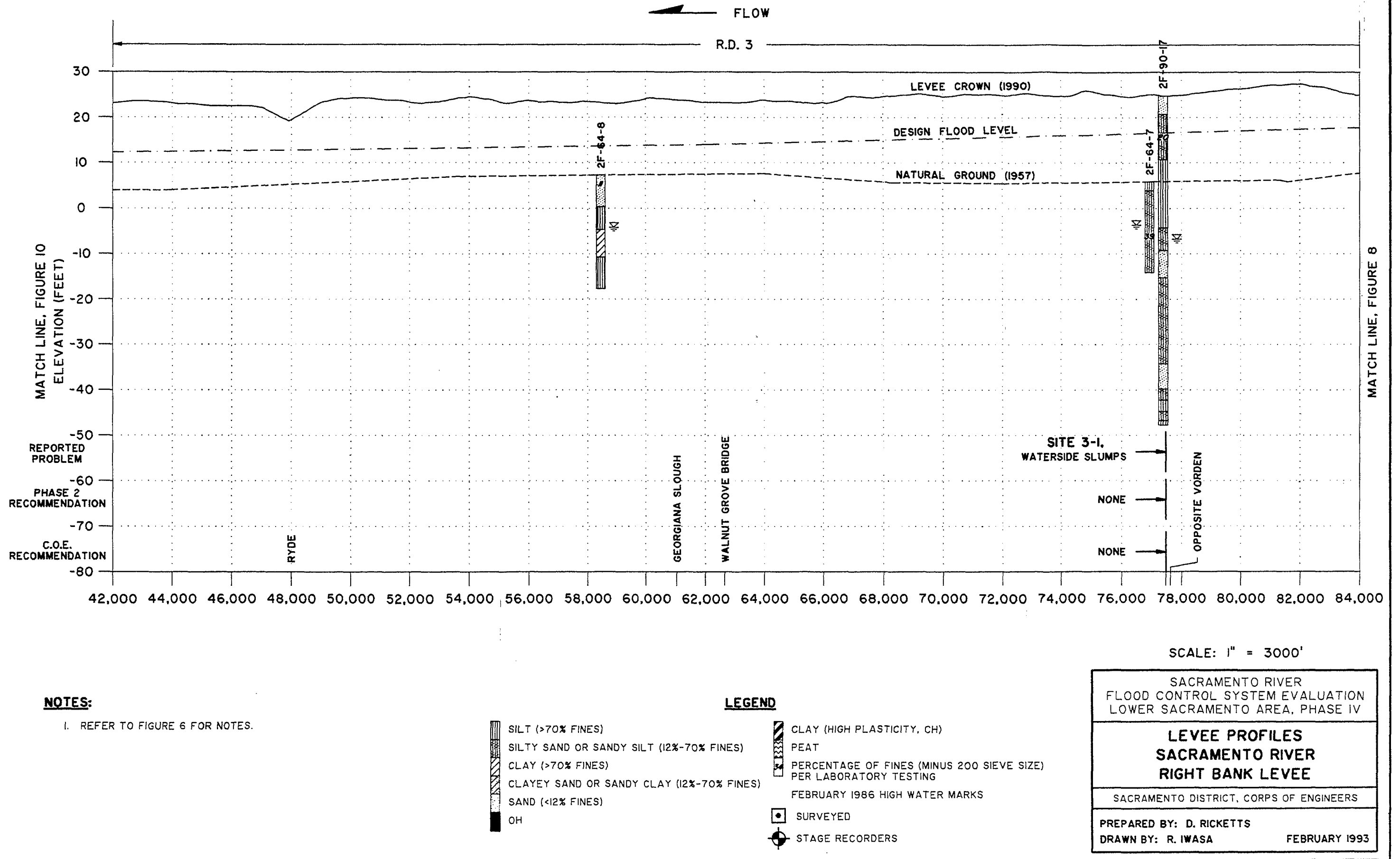


FIGURE 9

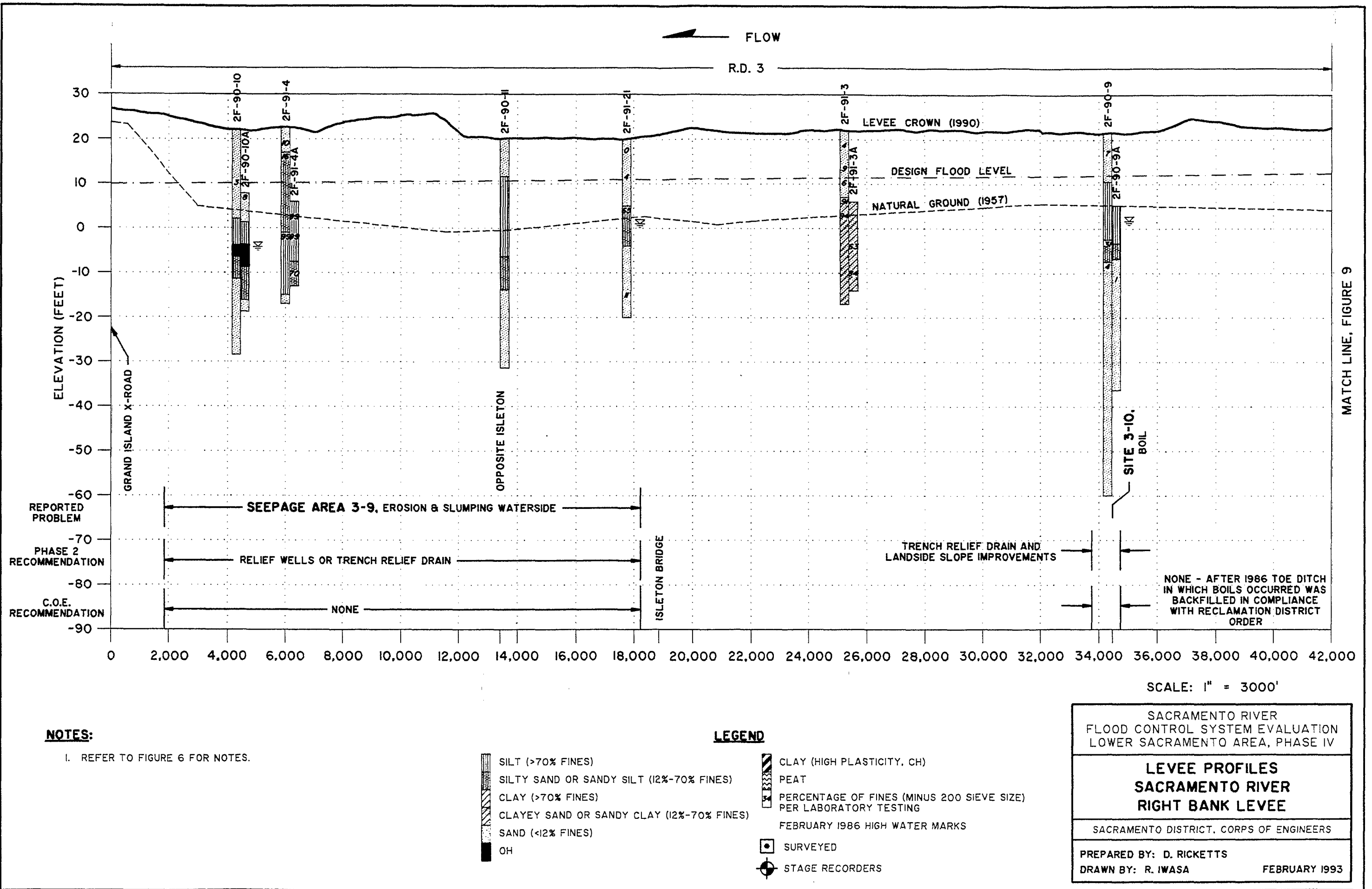
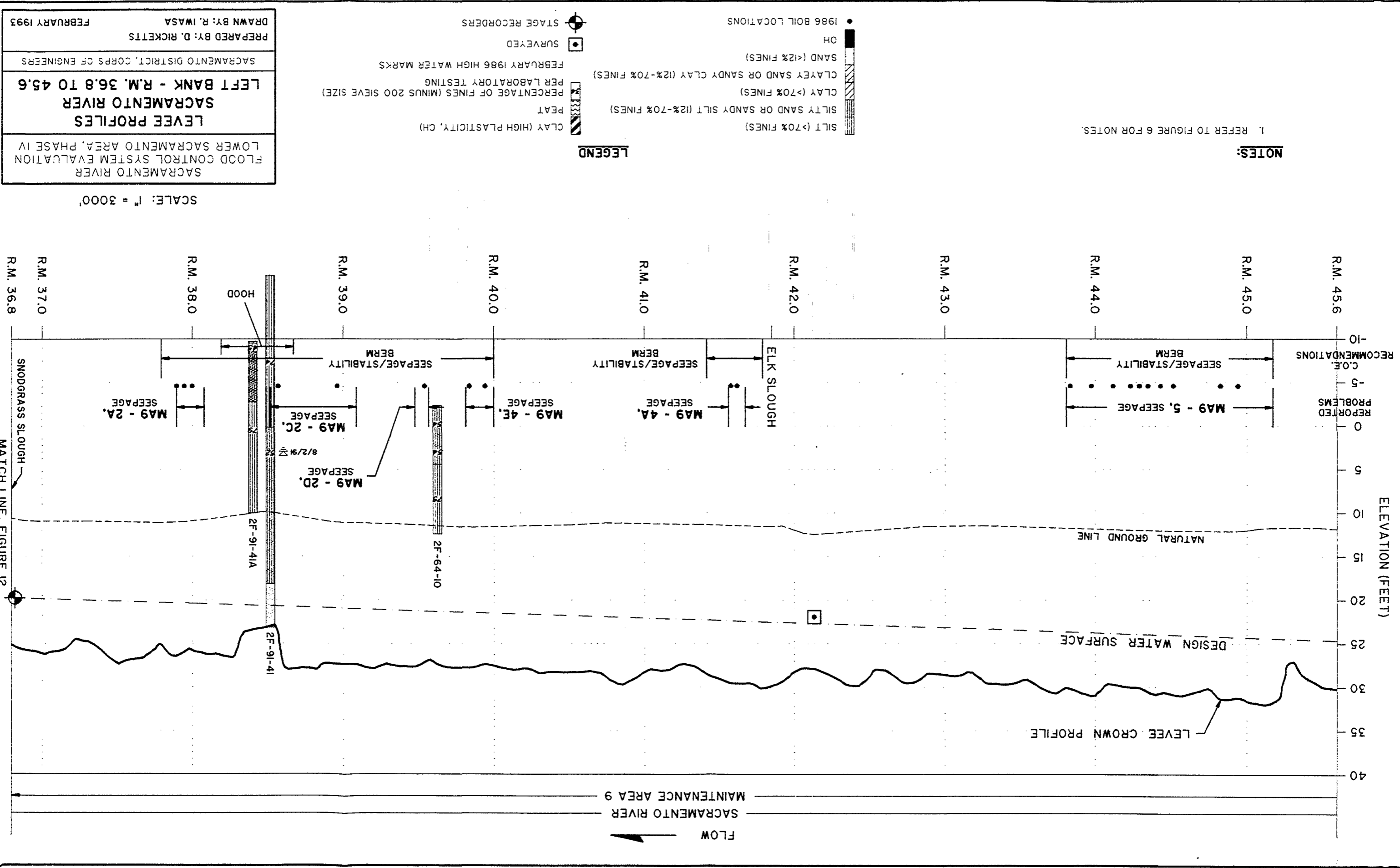


FIGURE 10



C-103573

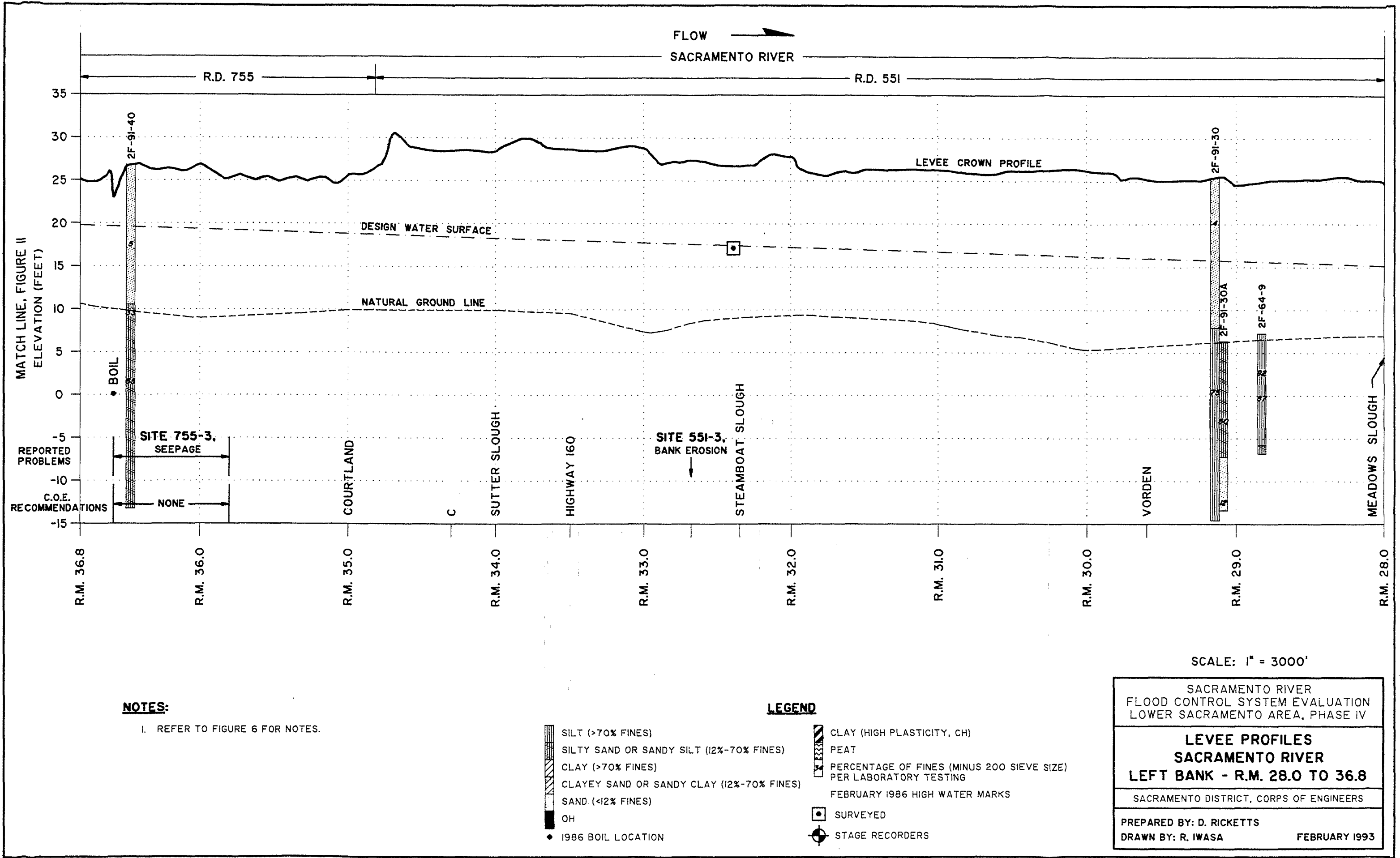
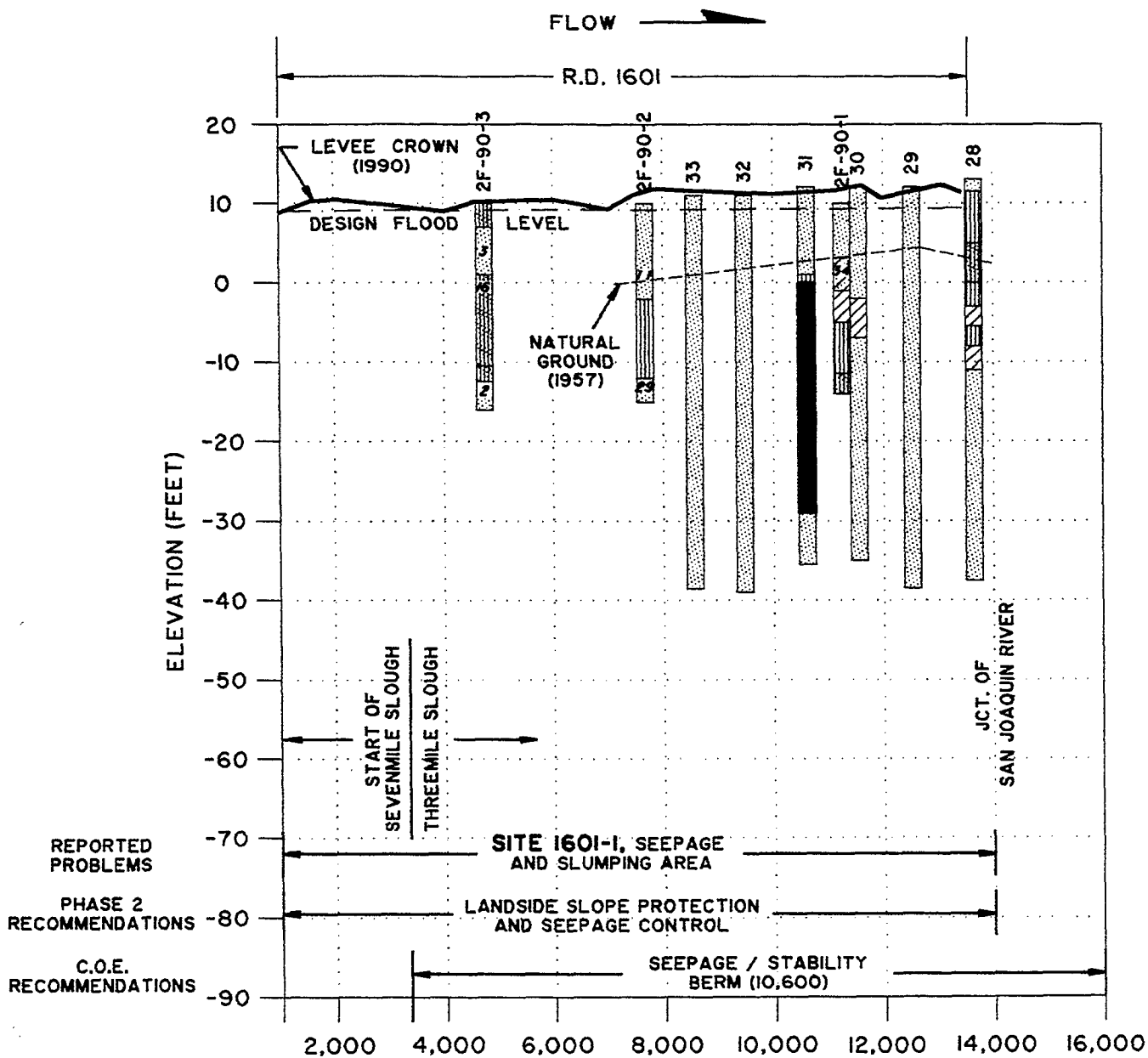


FIGURE 12



SCALE: 1" = 3000'

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

LEVEE PROFILES  
THREEMILE SLOUGH & A  
PORTION OF SEVENMILE SLOUGH  
EAST BANK LEVEE

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

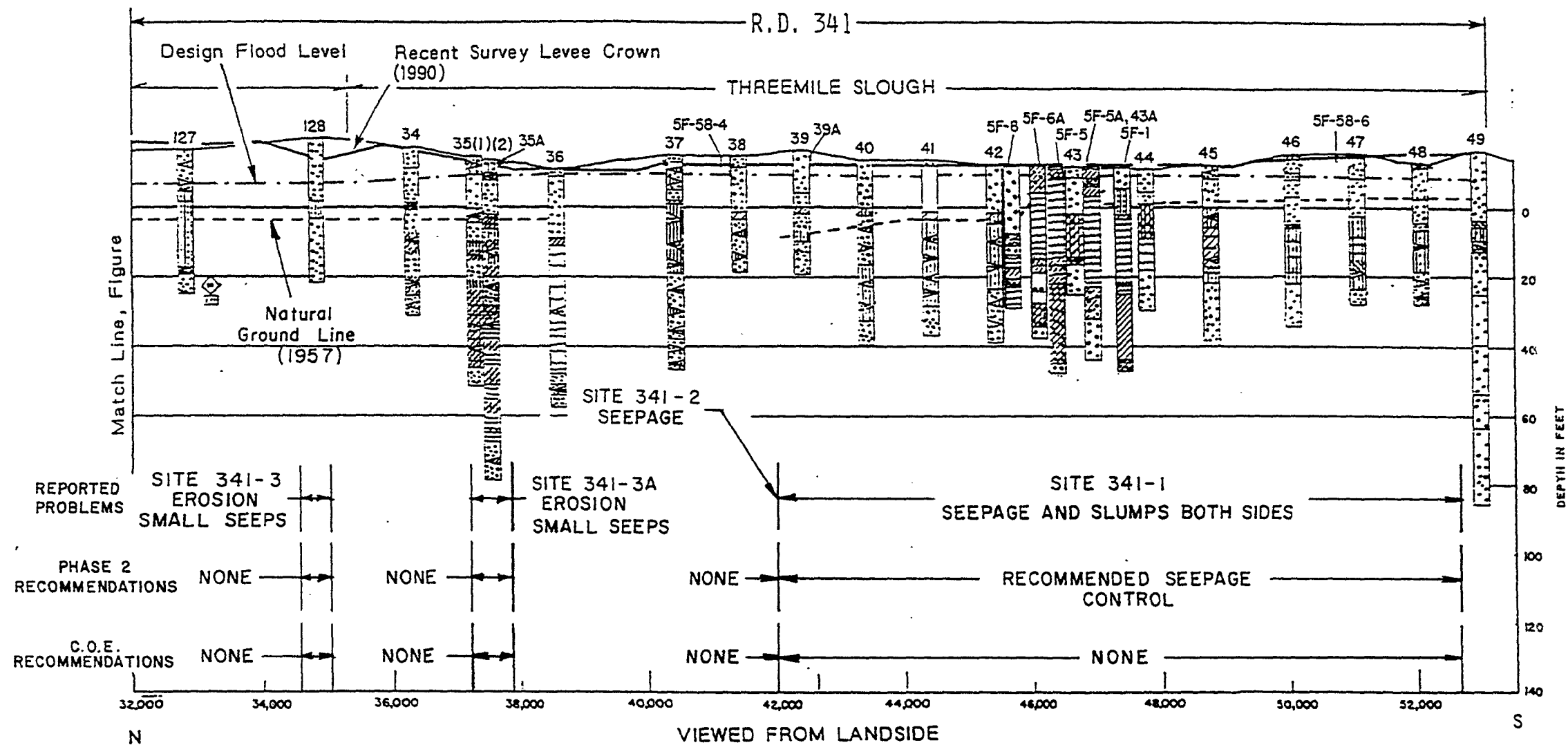
DRAWN BY: R. IWASA

FEBRUARY 1993

**NOTE:**

I. REFER TO FIGURE 6 FOR NOTES AND LEGEND.

FIGURE 13



LEGEND

— DRY (WET) DENSITY IN POUNDS PER CUBIC FOOT

· · · BLOWS PER FOOT (P. INDICATES PUSH)

▽ UNCONFINED COMPRESSIVE STRENGTH  $K_c$  Kg/cm<sup>2</sup>

△ UNCONFINED COMPRESSIVE STRESS AT 10% STRAIN,  $S_{10}$  Kg/cm<sup>2</sup>

⊕ LOSS ON IGNITION IN PERCENT

◇ MAXIMUM SIEVE SIZE RETAINING 50% OF SAMPLE BY WEIGHT .050

□ SPECIFIC GRAVITY

□ SAND

□ SILT

□ ORGANIC SILT

□ CLAY

□ ORGANIC CLAY

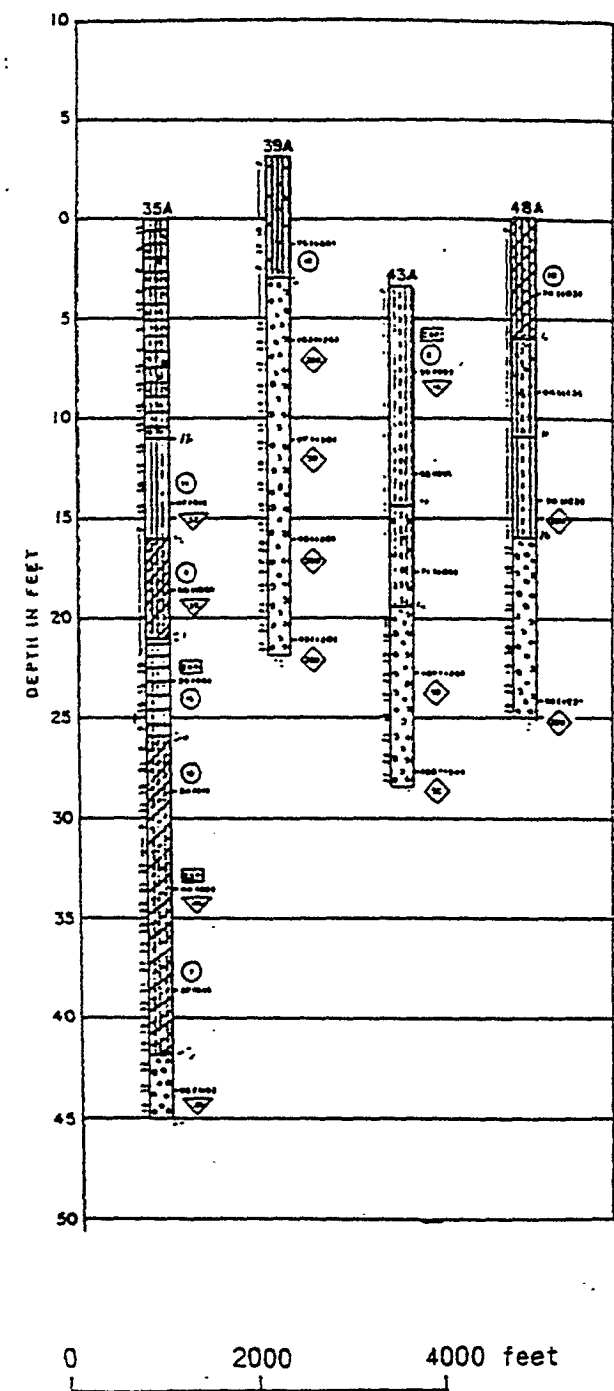
□ PEAT

□ COMPOSITE OF THE ABOVE MATERIAL - MAJOR CONSTITUENT DESIGNATED BY HEAVIER WEIGHT LINES OR CIRCLES, MINOR CONSTITUENTS BY LIGHTER WEIGHT LINES OR CIRCLES. BLOCK SHOWN IS CLAYEY SILT, ONE OF MANY POSSIBLE COMBINATIONS

□ STREAKS OF ONE MATERIAL IN ANOTHER; SAND WITH SILT STREAK.

□ LAYERS OF MATERIALS; LAYERS OF CLAY AND SILT.

Source: DWR, 1956.  
1990 DWR crown elevation shown where it differs from 1956 data.  
Elevations of channel bottom, natural ground and design flood level are approximate. Data obtained from U.S.A. C.O.E., S.D., 1957



SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

THREEMILE SLOUGH  
R.D. 341

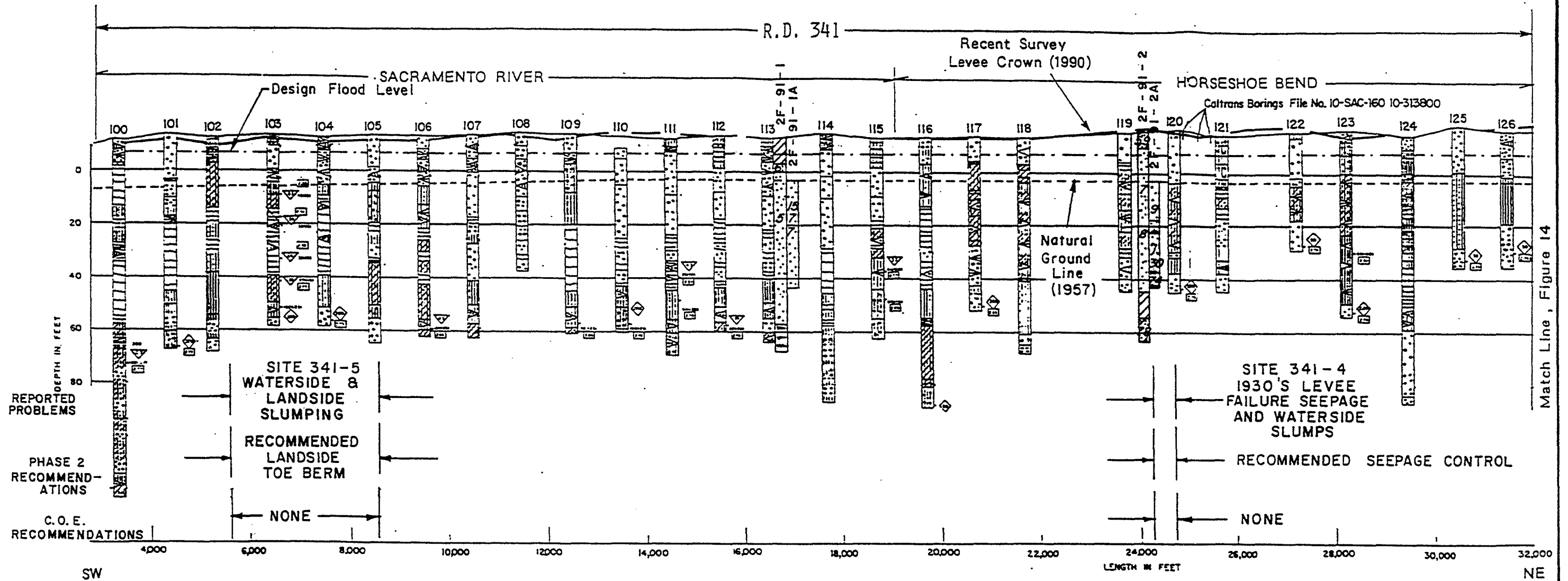
SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

DRAWN BY: R. IWASA

FEBRUARY 1993

FIGURE 14



0 Feet Depth Assumed to  
Equal 0 Feet Elevation

VIEWED FROM LANDSIDE

- LEGEND**
- DRY (WET) DENSITY IN POUNDS PER CUBIC FOOT
  - BLOWS PER FOOT (P. INDICATES PUSH)
  - ▽ UNCONFINED COMPRESSIVE STRENGTH  $q_u$ ,  $\text{Kg/cm}^2$
  - △ UNCONFINED COMPRESSIVE STRESS AT 10% STRAIN,  $S_{10}$ ,  $\text{Kg/cm}^2$
  - ⊕ LOSS ON IGNITION IN PERCENT
  - ◇ MAXIMUM SIEVE SIZE RETAINING 50% OF SAMPLE BY WEIGHT,  $D_{50}$
  - SPECIFIC GRAVITY
  - SAND
  - SILT

- ORGANIC SILT
- CLAY
- ORGANIC CLAY
- PEAT
- COMPOSITE OF THE ABOVE MATERIAL - MAJOR CONSTITUENT DESIGNATED BY HEAVIER WEIGHT LINES OR CIRCLES. MINOR CONSTITUENTS BY LIGHTER WEIGHT LINES OR CIRCLES. BLOCK SHOWN IS CLAYEY SILT, ONE OF MANY POSSIBLE COMBINATIONS.
- STREAKS OF ONE MATERIAL IN ANOTHER; SAND WITH SILT STREAK.
- LAYERS OF MATERIALS; LAYERS OF CLAY AND SILT.

Source: DWR, 1956.  
1990 DWR crown elevation  
shown where it differs  
from 1956 data.  
Elevations of channel  
bottom, natural ground  
and design flood level  
are approximate. Data  
obtained from U.S.A.  
C.O.E., S.D., 1957

0 2000 4000 feet

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

SACRAMENTO RIVER  
R.D. 341

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS  
DRAWN BY: R. IWASA

FEBRUARY 1993

FIGURE 15

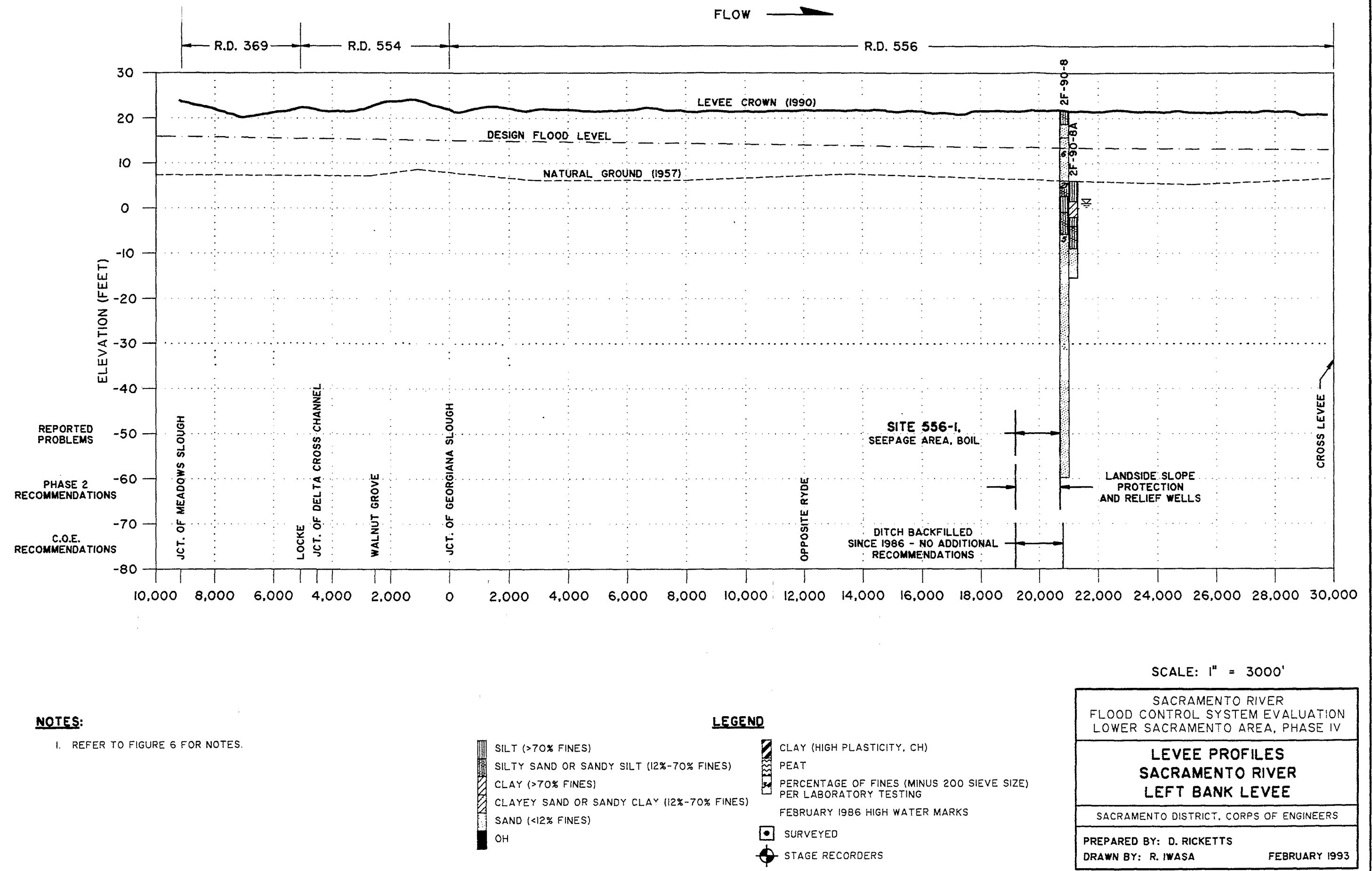
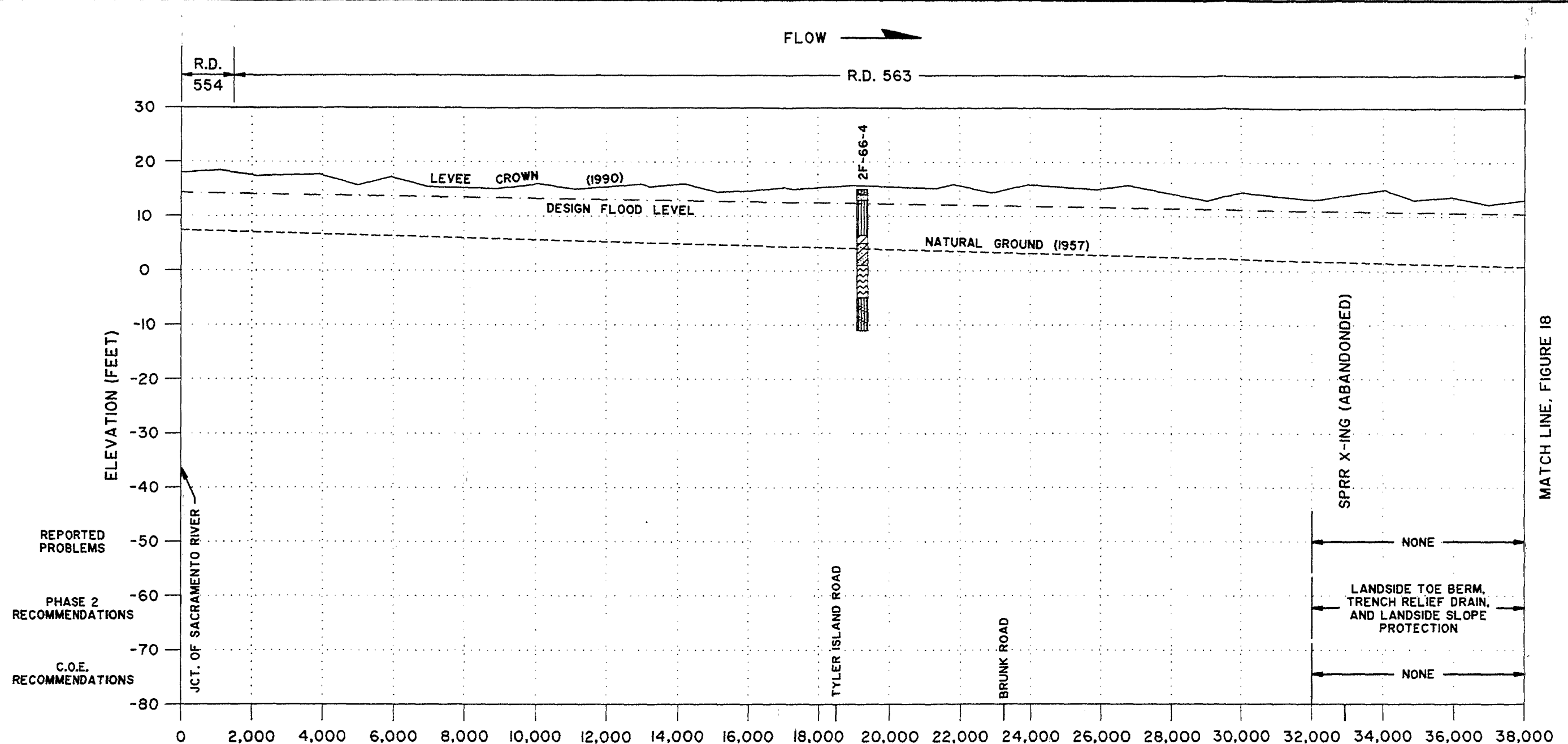


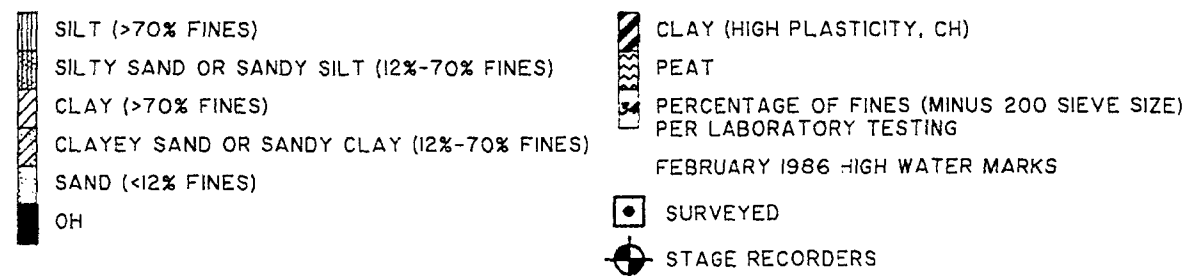
FIGURE 16

C-103578



**NOTES:**

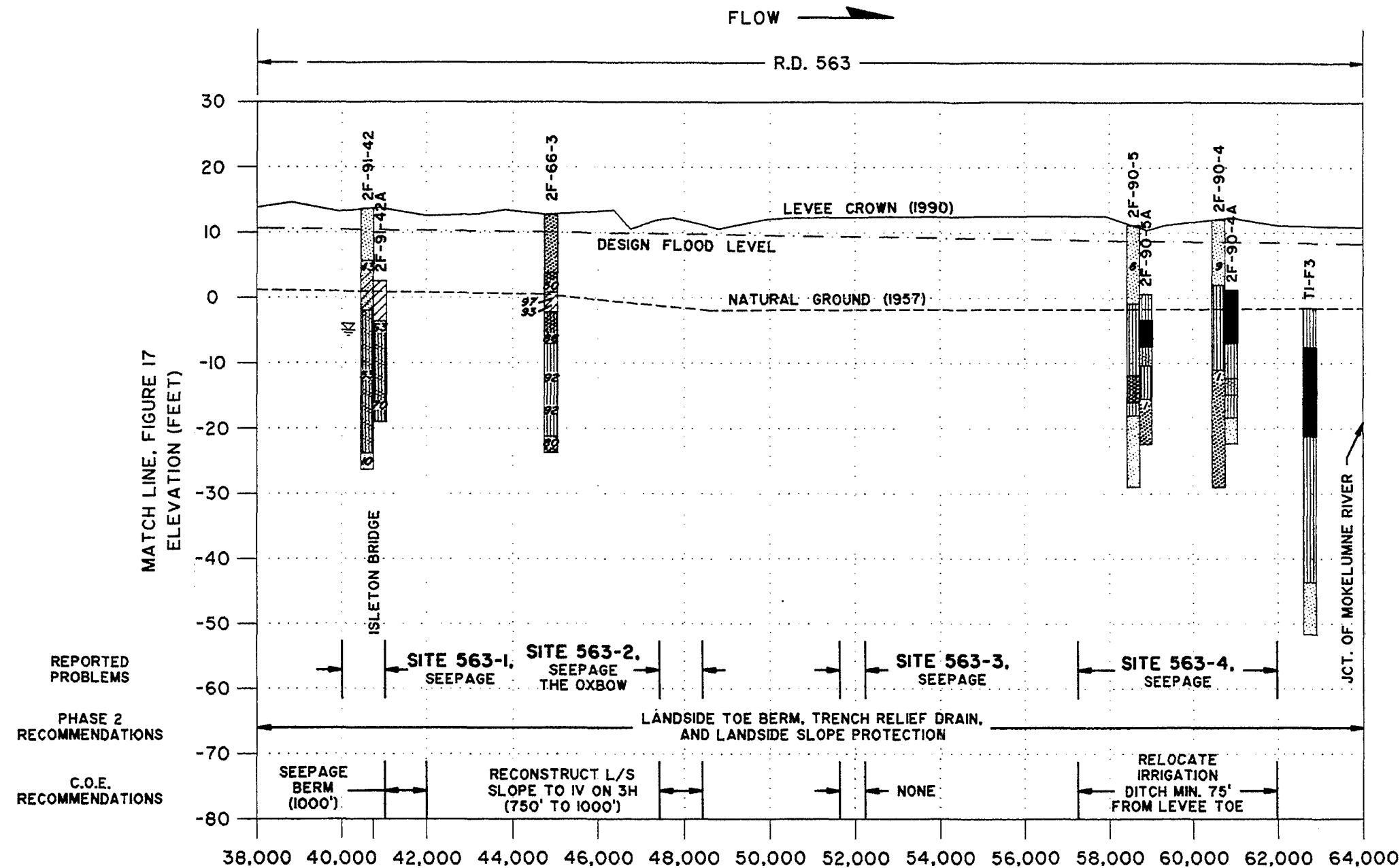
1. REFER TO FIGURE 6 FOR NOTES.



SCALE: 1" = 3000'

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION LOWER SACRAMENTO AREA, PHASE IV	
<b>LEVEE PROFILES GEORGIANA SLOUGH LEFT BANK LEVEE</b>	
SACRAMENTO DISTRICT, CORPS OF ENGINEERS	
PREPARED BY: D. RICKETTS	
DRAWN BY: R. IWASA	FEBRUARY 1993

FIGURE 17



**NOTES:**

I. REFER TO FIGURE 6 FOR NOTES.

SCALE: 1" = 3000'

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**LEVEE PROFILES  
GEORGIANA SLOUGH  
LEFT BANK LEVEE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

DRAWN BY: R. IWASA

FEBRUARY 1993

FIGURE 18

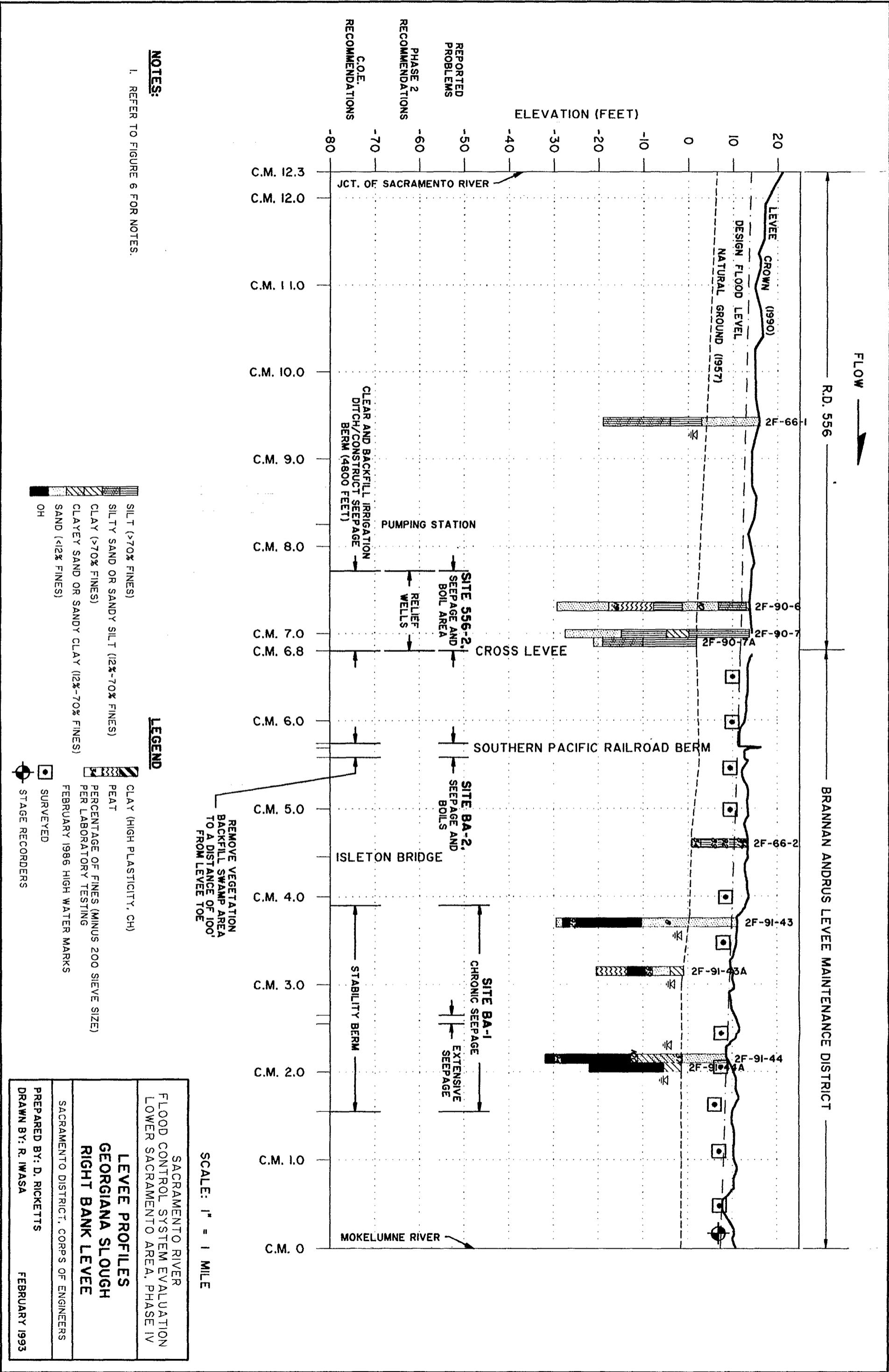
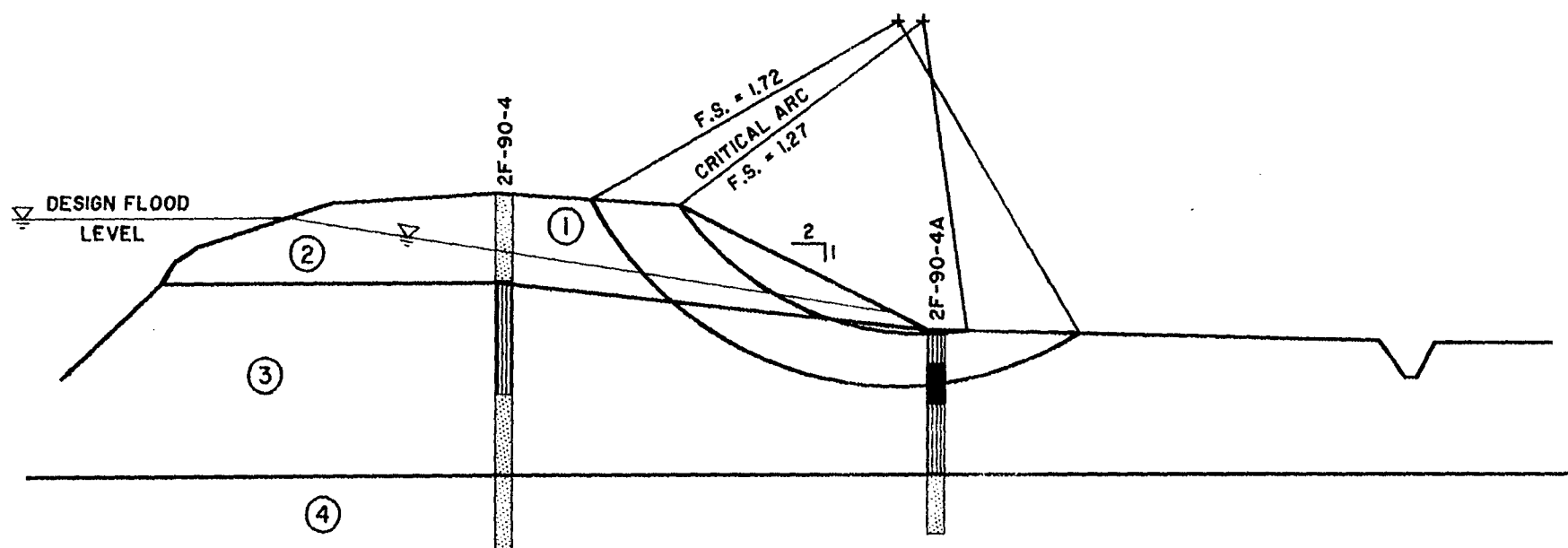


FIGURE 19



SCALE: 1" = 20'

ZONE	MATERIAL	TOTAL UNIT WT. (PCF)	FRICTION ANGLE (DEGREES)	COHESION (PCF)
1	SAND	100	30°	0
2	SAND	118	30°	0
3	SILT/SANDY SILT	90	28°	0
4	SAND	118	30°	0

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**STABILITY ANALYSIS  
SITE 563-4**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

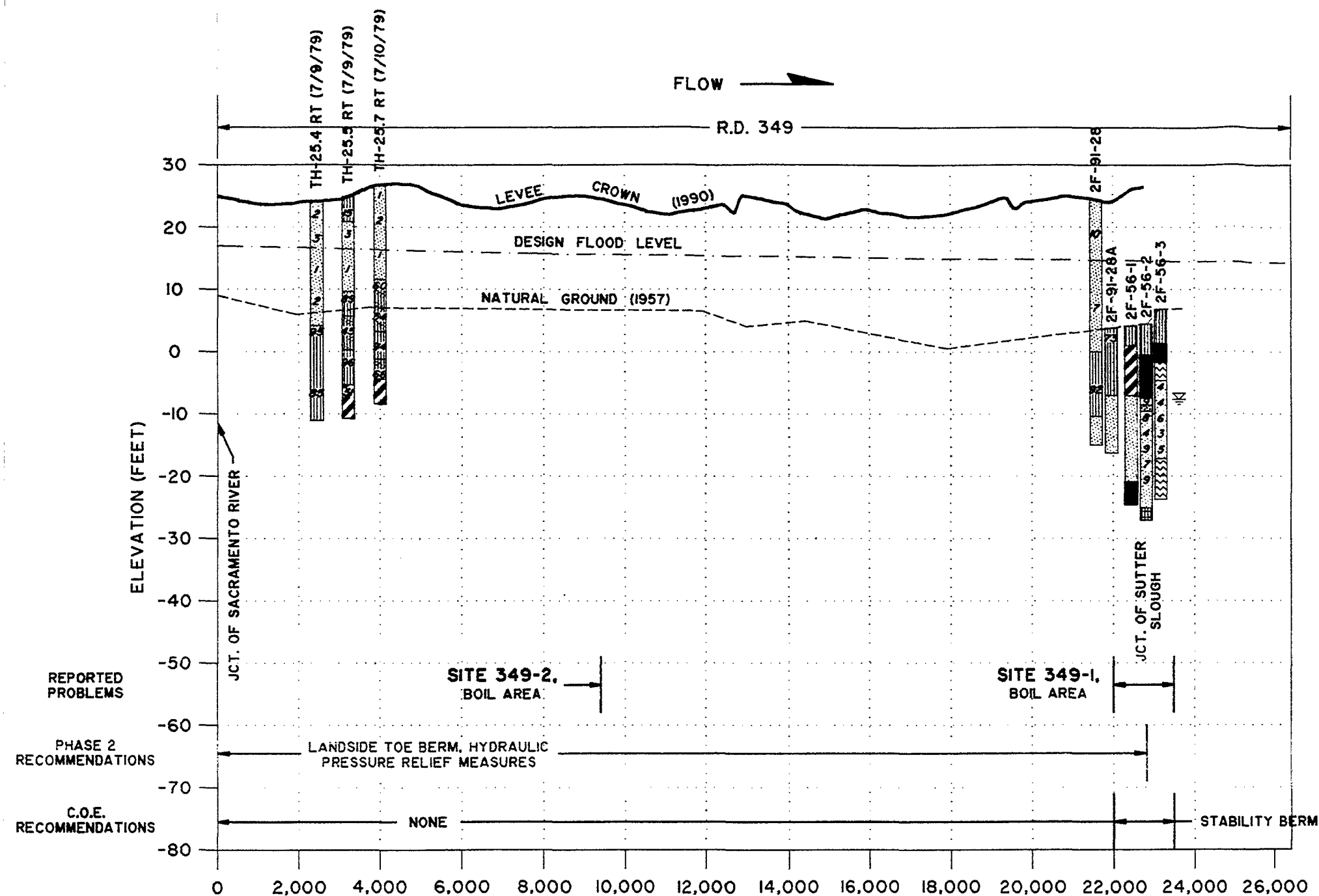
PREPARED BY: D. RICKETTS

DRAWN BY: R. IWASA

FEBRUARY 1993

C-103582

FIGURE 19A



**NOTES:**

I. REFER TO FIGURE 6 FOR NOTES.

SILT (>70% FINES)  
 SILTY SAND OR SANDY SILT (12%-70% FINES)  
 CLAY (>70% FINES)  
 CLAYEY SAND OR SANDY CLAY (12%-70% FINES)  
 SAND (<12% FINES)  
 OH

**LEGEND**

CLAY (HIGH PLASTICITY, CH)  
 PEAT  
 PERCENTAGE OF FINES (MINUS 200 SIEVE SIZE) PER LABORATORY TESTING  
 FEBRUARY 1986 HIGH WATER MARKS  
 SURVEYED  
 STAGE RECORDERS

SCALE: 1" = 3000'

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

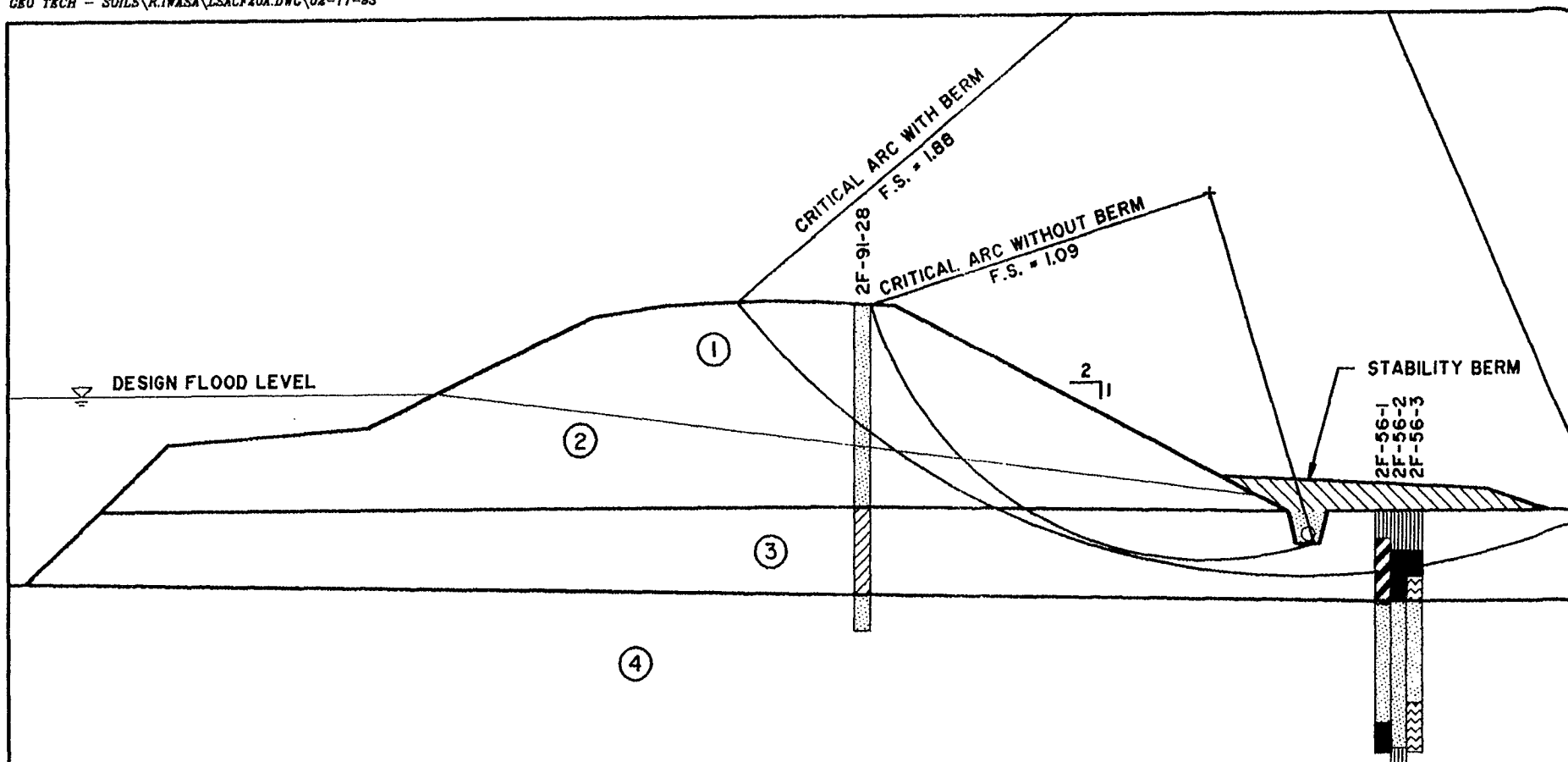
**LEVEE PROFILES  
STEAMBOAT SLOUGH  
RIGHT BANK LEVEE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS  
DRAWN BY: R. IWASA

FEBRUARY 1993

FIGURE 20



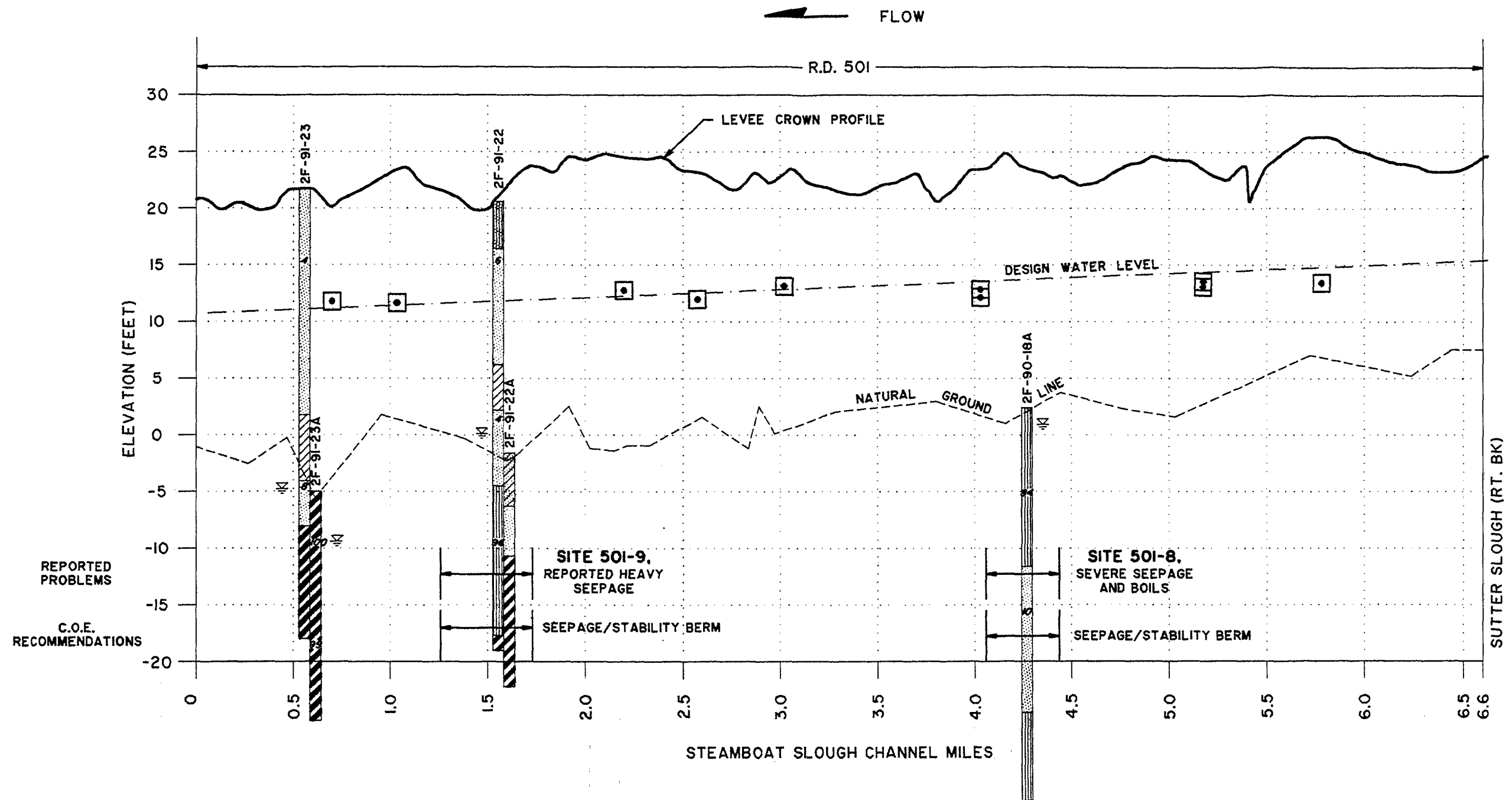
SCALE: 1" = 20'

ZONE	MATERIAL	TOTAL UNIT WT. (PCF)	FRICTION ANGLE (DEGREES)	COHESION (PCF)
1	SAND	100	30°	0
2	SAND	118	30°	0
3	SILT/ORGANIC CLAY	90	25°	100
4	SAND	118	30°	0

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION LOWER SACRAMENTO AREA, PHASE IV	
<b>STABILITY ANALYSIS</b> <b>SITE 349-1</b>	
SACRAMENTO DISTRICT, CORPS OF ENGINEERS	
PREPARED BY: D. RICKETTS	
DRAWN BY: R. IWASA	FEBRUARY 1993

FIGURE 20A

C-103584



SCALE: 1" = 3000'

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**LEVEE PROFILES  
STEAMBOAT SLOUGH  
RIGHT BANK LEVEE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

DRAWN BY: R. IWASA

FEBRUARY 1993

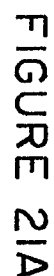
**NOTES:**

1. REFER TO FIGURE 6 FOR NOTES.

**LEGEND**

- SILT (>70% FINES)
- SILTY SAND OR SANDY SILT (12%-70% FINES)
- CLAY (>70% FINES)
- CLAYEY SAND OR SANDY CLAY (12%-70% FINES)
- SAND (<12% FINES)
- OH
- CLAY (HIGH PLASTICITY, CH)
- PEAT
- PERCENTAGE OF FINES (MINUS 200 SIEVE SIZE) PER LABORATORY TESTING
- FEBRUARY 1986 HIGH WATER MARKS
- SURVEYED
- STAGE RECORDERS

FIGURE 21

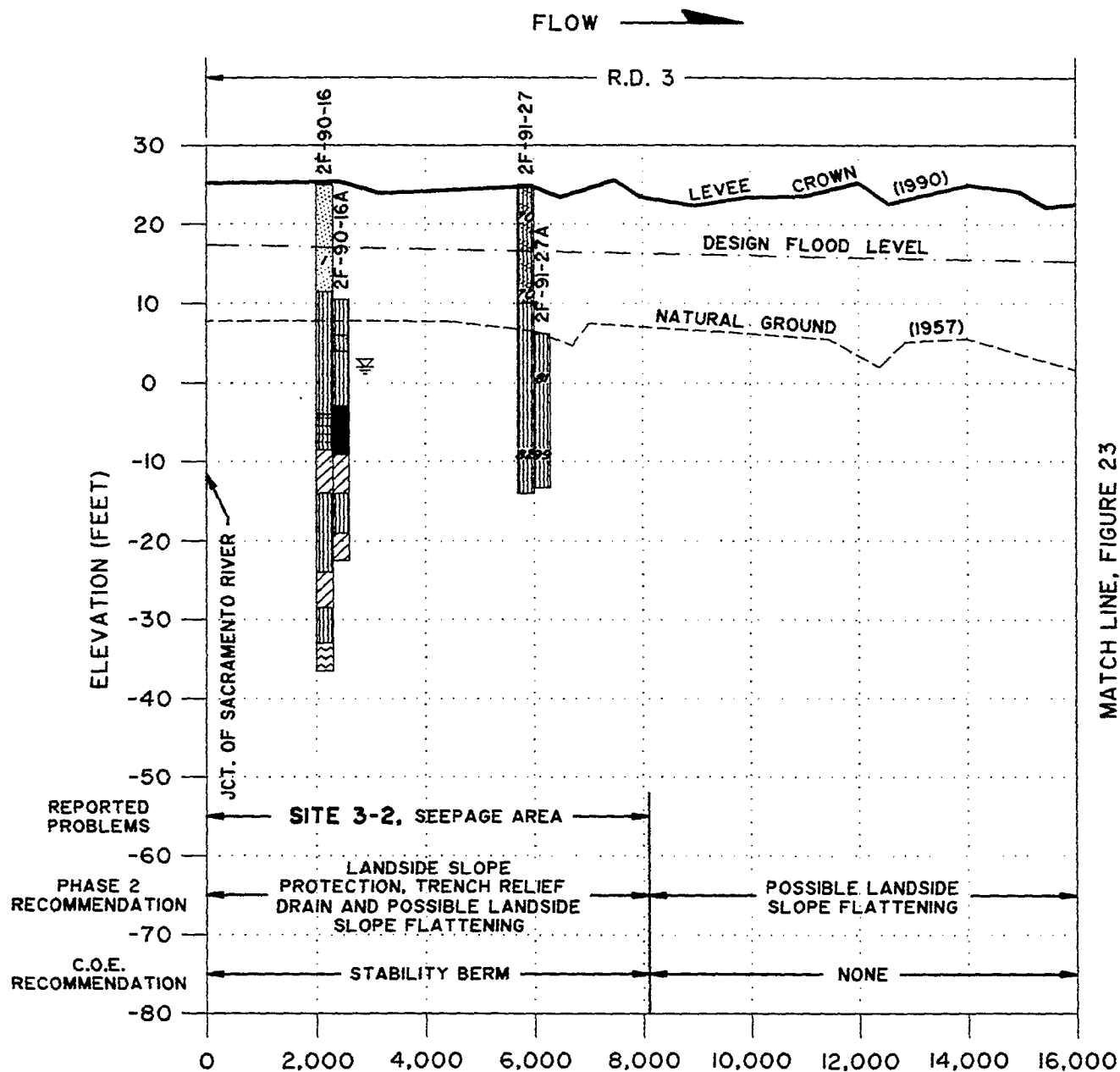

$$\begin{aligned} n_f &= 2 & n_d &= 8 \\ \Delta h &= \frac{14}{8} = 1.75 \\ l_e &= \frac{1.75 \text{ ft}}{5 \text{ ft}} = 0.35 \\ l_c &= \frac{G_s - 1}{1 + e} = \frac{2.72 - 1}{1 + 0.85} = 0.93 \\ \text{F.S.} &= \frac{l_c}{l_e} = 2.66 \end{aligned}$$

## SEEPAGE ANALYSIS

### SITE 50I-9

PREPARED BY: D. RICKETTS  
DRAWN BY: R. IWASA

JANUARY 1993



SCALE: 1" = 3000'

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**LEVEE PROFILES  
STEAMBOAT SLOUGH  
LEFT BANK LEVEE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS  
DRAWN BY: R. IWASA

FEBRUARY 1993

**NOTE:**

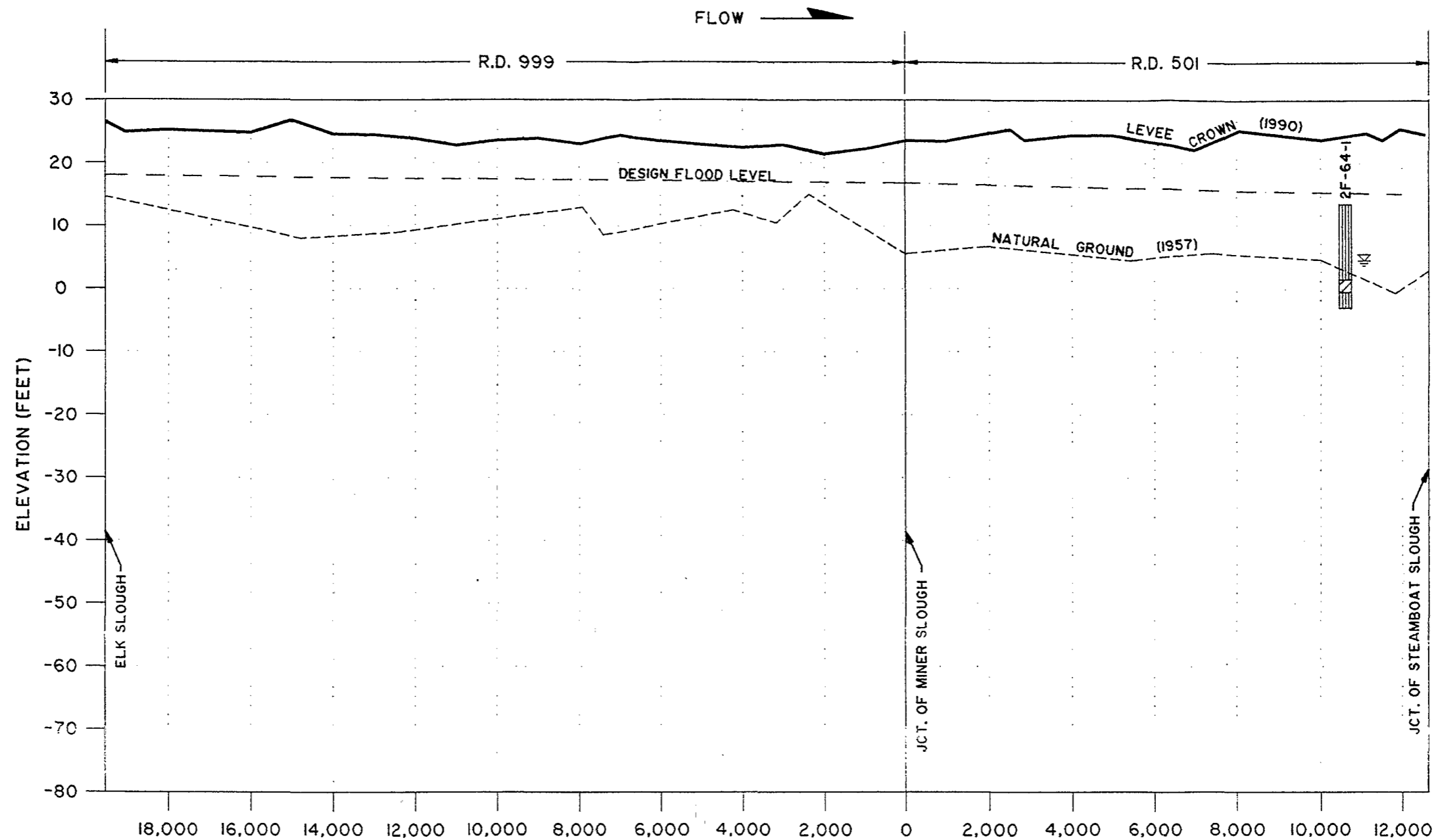
I. REFER TO FIGURE 6 FOR NOTES AND LEGEND.

FIGURE 22

C-103587

C-103587





**NOTES:**

1. REFER TO FIGURE 6 FOR NOTES.

**LEGEND**

- |  |   |  |  |
|--|---|--|--|
|  | SILT (>70% FINES)                         |  | CLAY (HIGH PLASTICITY, CH)   |
|  | SILTY SAND OR SANDY SILT (12%-70% FINES)  |  | PEAT   |
|  | CLAY (>70% FINES)                         |  | PERCENTAGE OF FINES (MINUS 200 SIEVE SIZE)<br>PER LABORATORY TESTING |
|  | CLAYEY SAND OR SANDY CLAY (12%-70% FINES) |  | FEBRUARY 1966 HIGH WATER MARKS                                       |
|  | SAND (<12% FINES)                         |  | SURVEYED   |
|  | OH  |  | STAGE RECORDERS  |

SCALE: 1" = 3000'

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**LEVEE PROFILES  
SUTTER SLOUGH  
RIGHT BANK LEVEE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

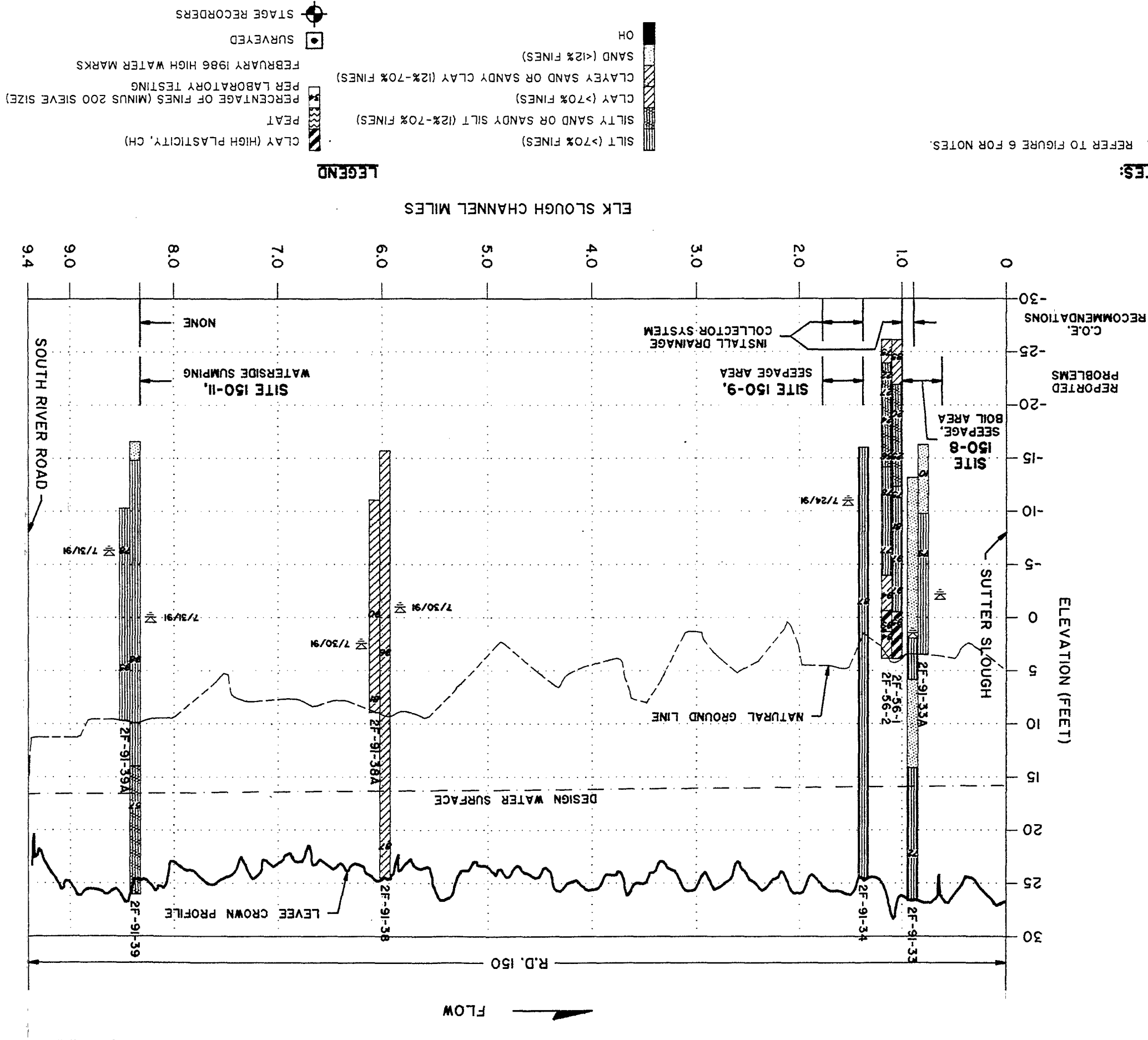
DRAWN BY: R. IWASA

FEBRUARY 1993

**FIGURE 24**

NOTES:

1. REFER TO FIGURE 6 FOR NOTES.



SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

LEVEE PROFILES  
ELK SLOUGH  
LEFT BANK LEVEE

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

DRAWN BY: R. IWASA

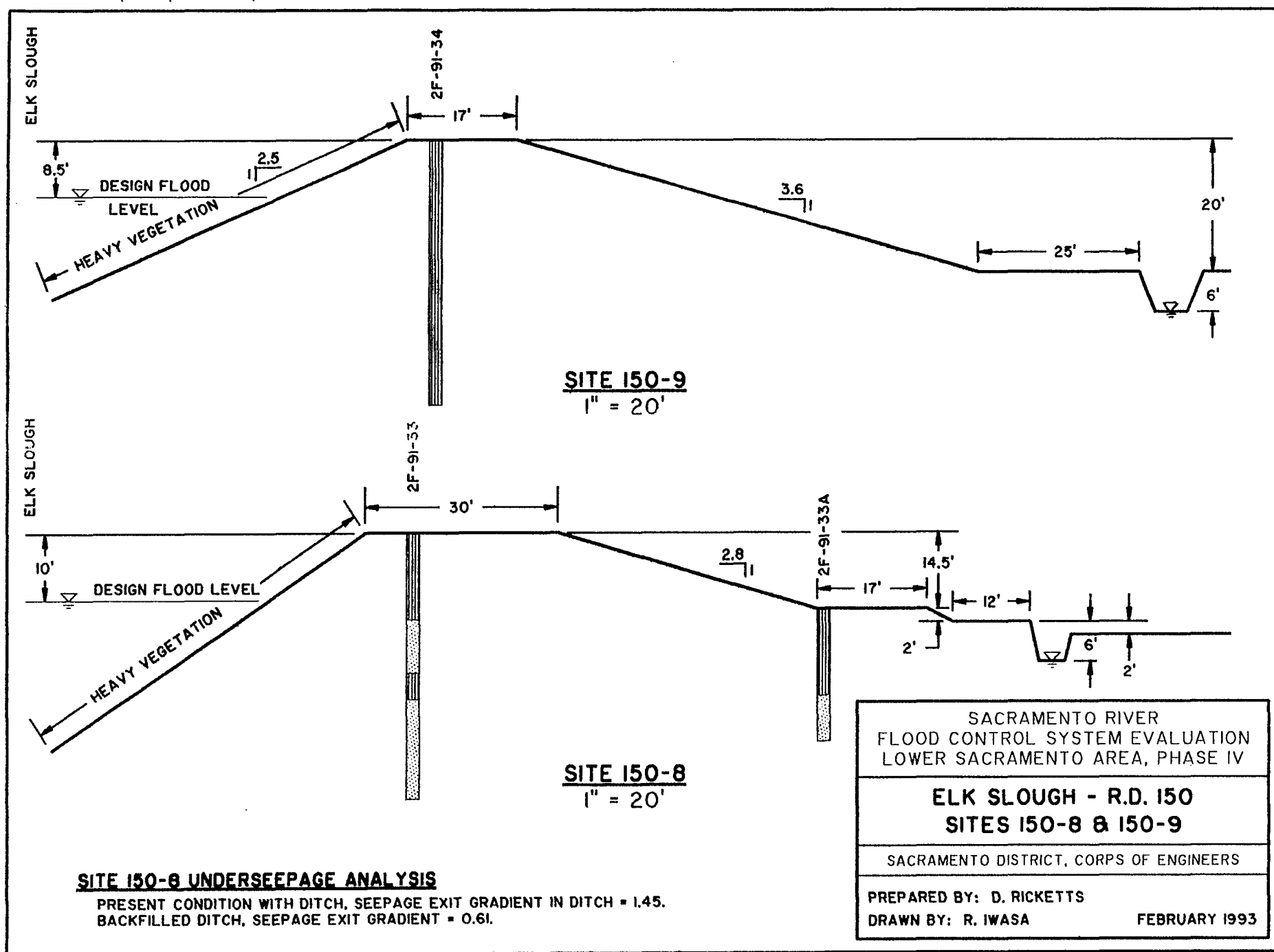
FEBRUARY 1993

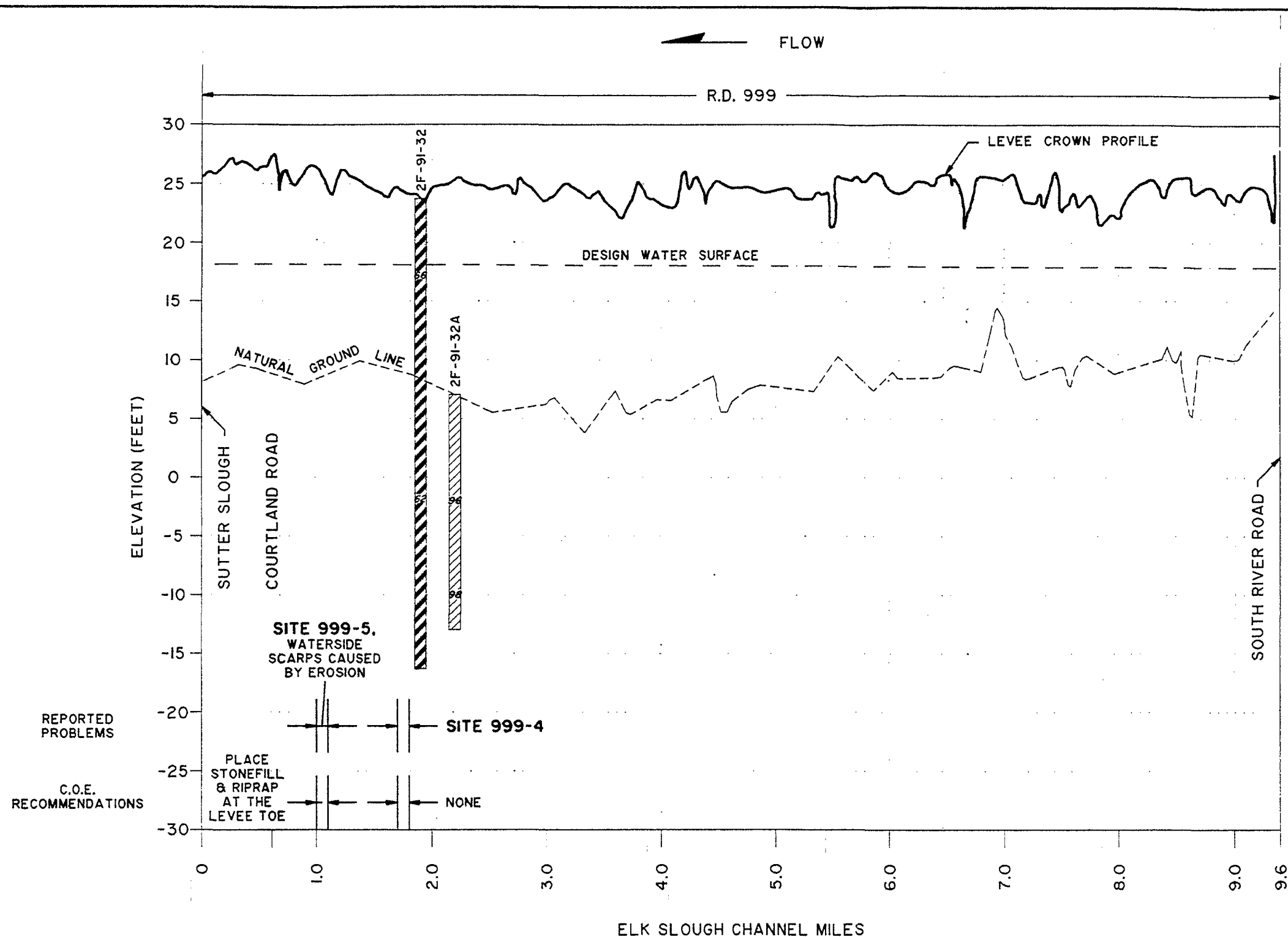
FIGURE 25

C-103590

C-103591

FIGURE 25A





**NOTES:**

1. REFER TO FIGURE 6 FOR NOTES.

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

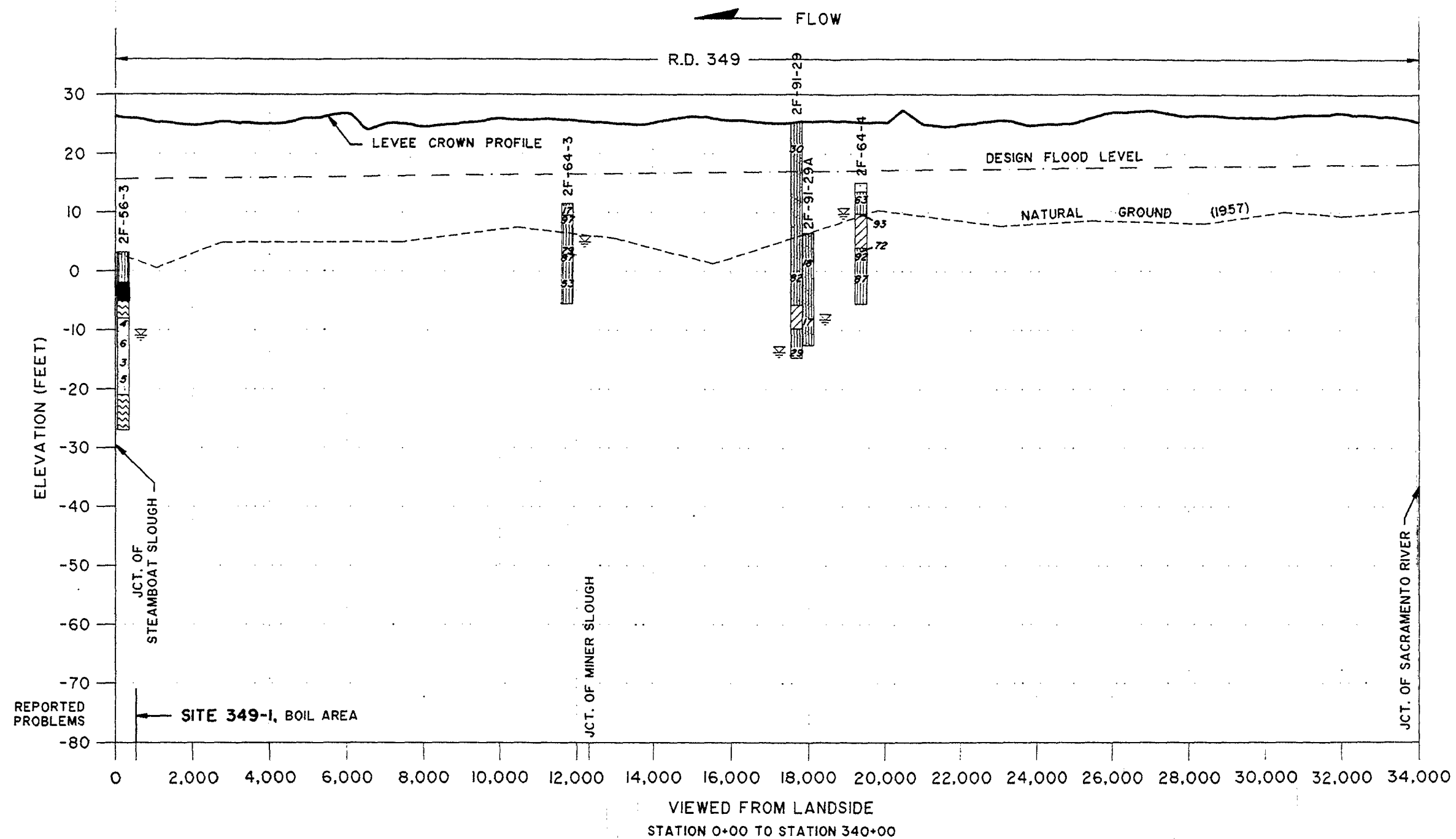
**LEVEE PROFILES  
ELK SLOUGH  
RIGHT BANK LEVEE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS  
DRAWN BY: R. IWASA

FEBRUARY 1993

FIGURE 26



**NOTES:**

1. REFER TO FIGURE 6 FOR NOTES

**LEGEND**

- |  |   |  |  |
|--|---|--|--|
|  | SILT (>70% FINES)                         |  | CLAY (HIGH PLASTICITY, CH)   |
|  | SILTY SAND OR SANDY SILT (12%-70% FINES)  |  | PEAT   |
|  | CLAY (>70% FINES)                         |  | PERCENTAGE OF FINES (MINUS 200 SIEVE SIZE)<br>PER LABORATORY TESTING |
|  | CLAYEY SAND OR SANDY CLAY (12%-70% FINES) |  | FEBRUARY 1986 HIGH WATER MARKS                                       |
|  | SAND (<12% FINES)                         |  | SURVEYED   |
|  | OH  |  | STAGE RECORDERS  |

SCALE: 1" = 3000'

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**LEVEE PROFILES  
SUTTER SLOUGH  
LEFT BANK LEVEE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

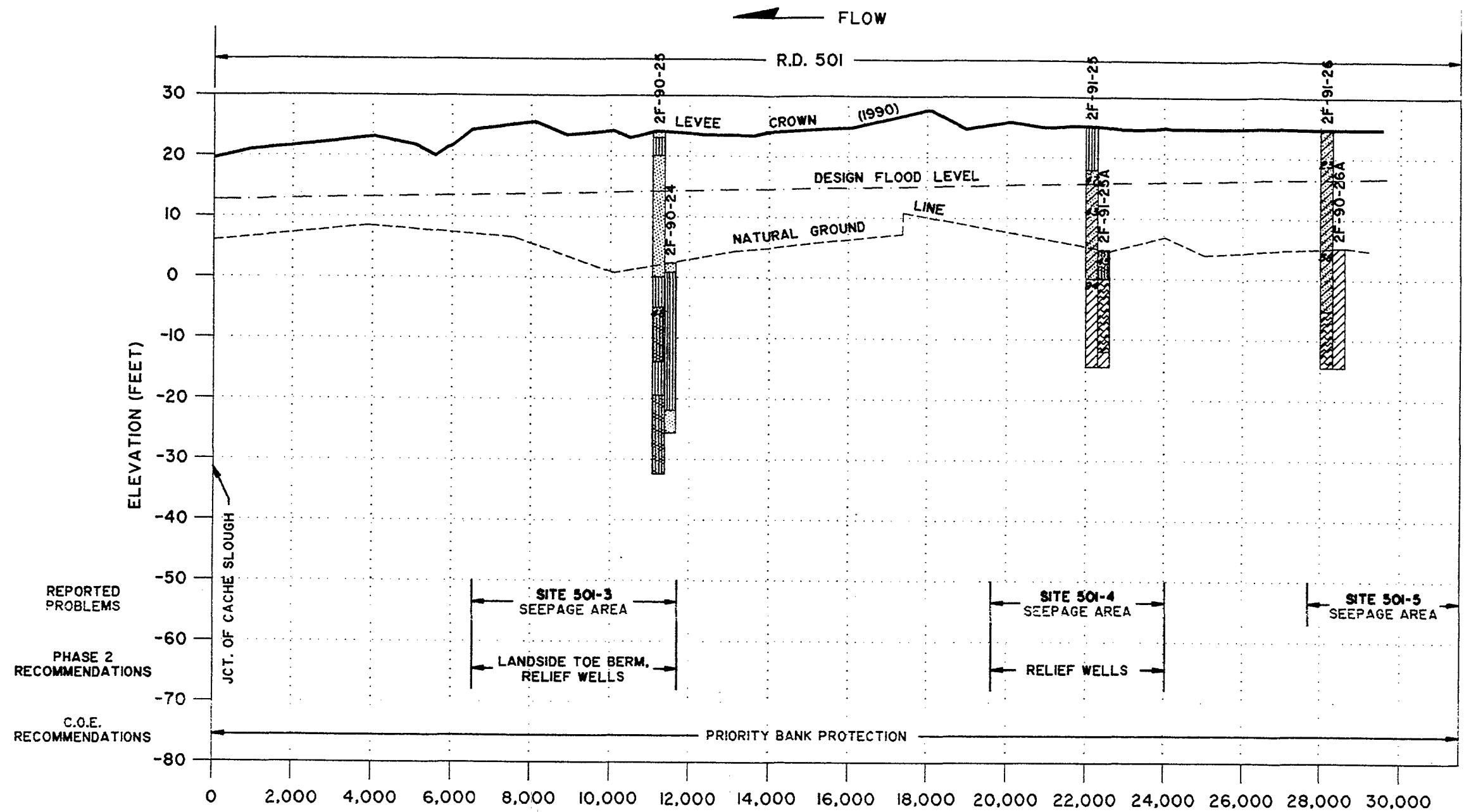
DRAWN BY: R. IWASA

FEBRUARY 1993

FIGURE 27

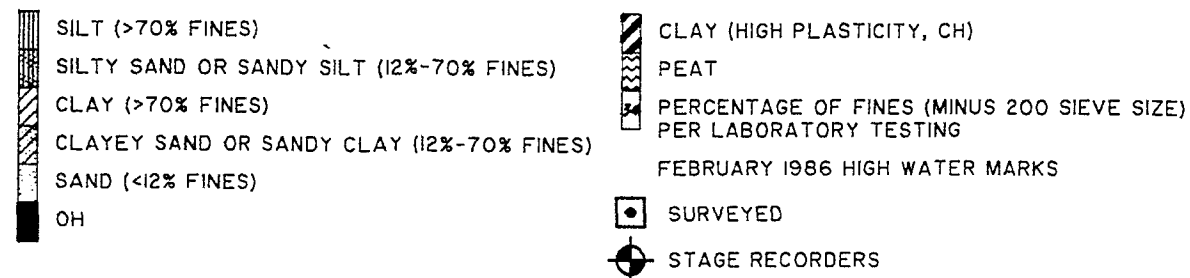
C-103593

C-103593



**NOTES:**

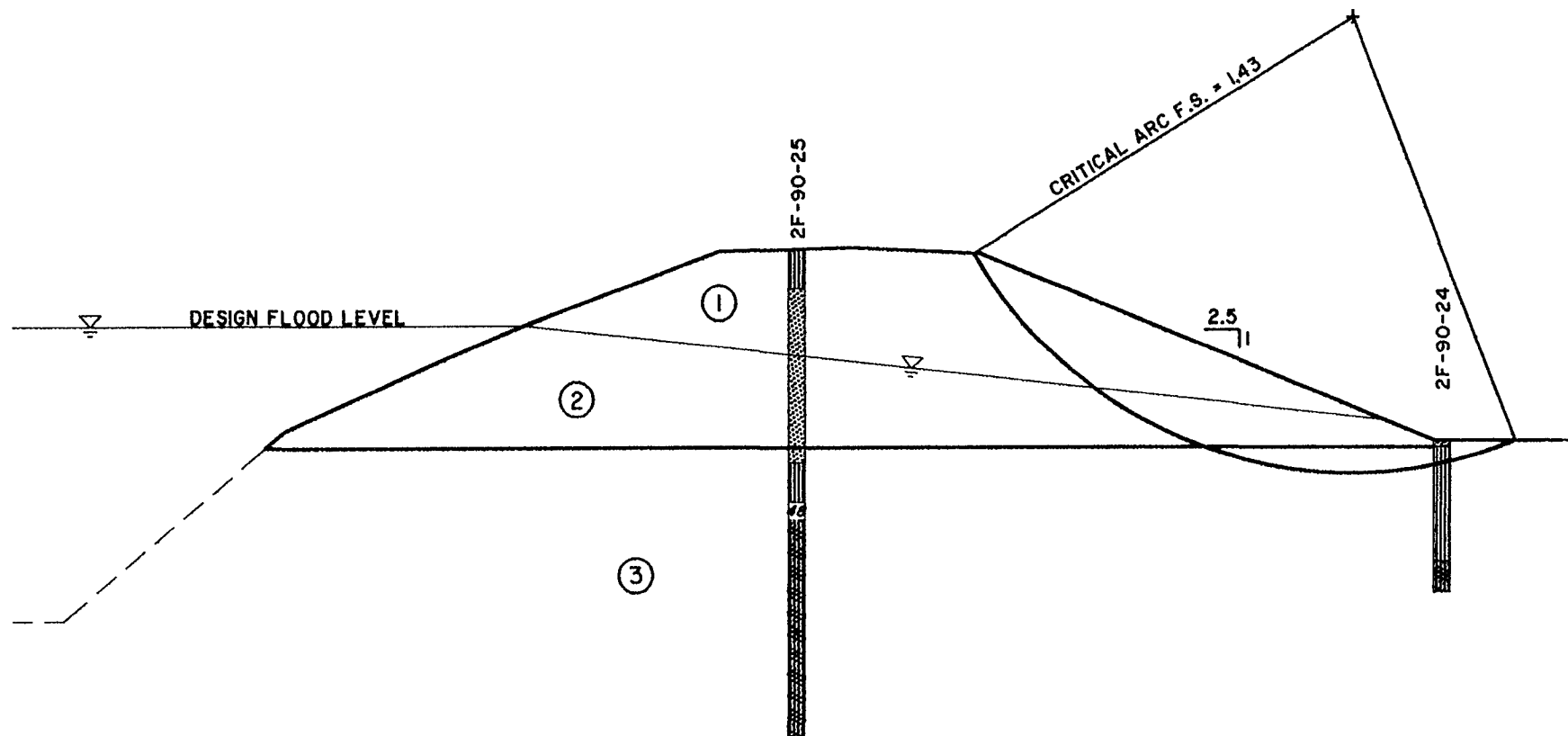
I. REFER TO FIGURE 6 FOR NOTES.



SCALE: 1" = 3000'

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION LOWER SACRAMENTO AREA, PHASE IV	
<b>LEVEE PROFILES MINER SLOUGH LEFT BANK LEVEE</b>	
SACRAMENTO DISTRICT, CORPS OF ENGINEERS	
PREPARED BY: D. RICKETTS DRAWN BY: R. IWASA	FEBRUARY 1993

FIGURE 28



SCALE: 1" = 20'

ZONE	MATERIAL	TOTAL UNIT WT. (PCF)	FRICTION ANGLE (DEGREES)	COHESION (PCF)
1	SAND	100	30°	0
2	SAND	118	30°	0
3	SILT/SANDY SILT	100	25°	100

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**STABILITY ANALYSIS  
SITE 50I-3**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

DRAWN BY: R. IWASA

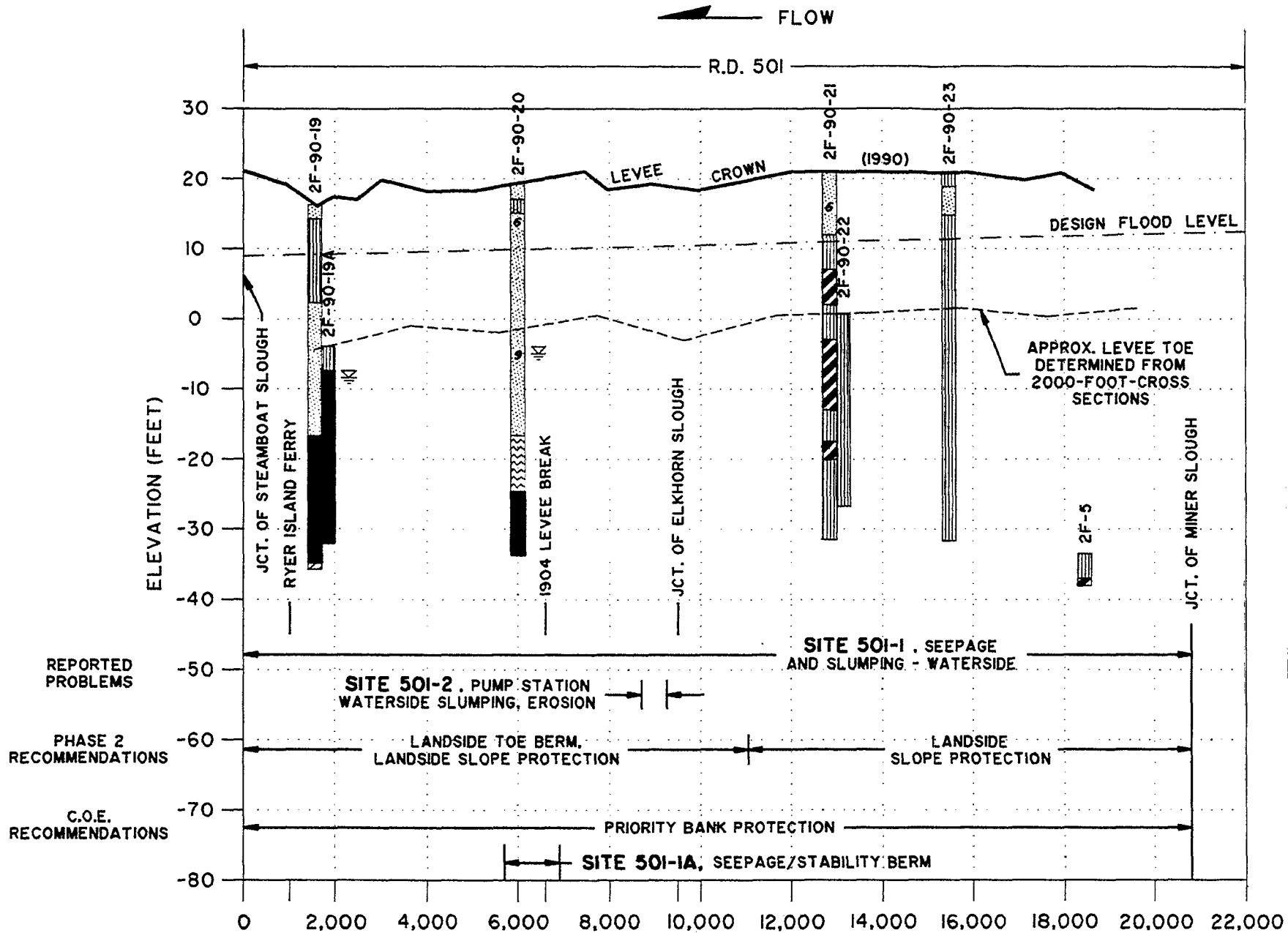
FEBRUARY 1993

FIGURE 28A

C-103595

C-103595

**NOTES:**  
1. REFER TO FIGURE 6 FOR NOTES.



SCALE: 1" = 3000'

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

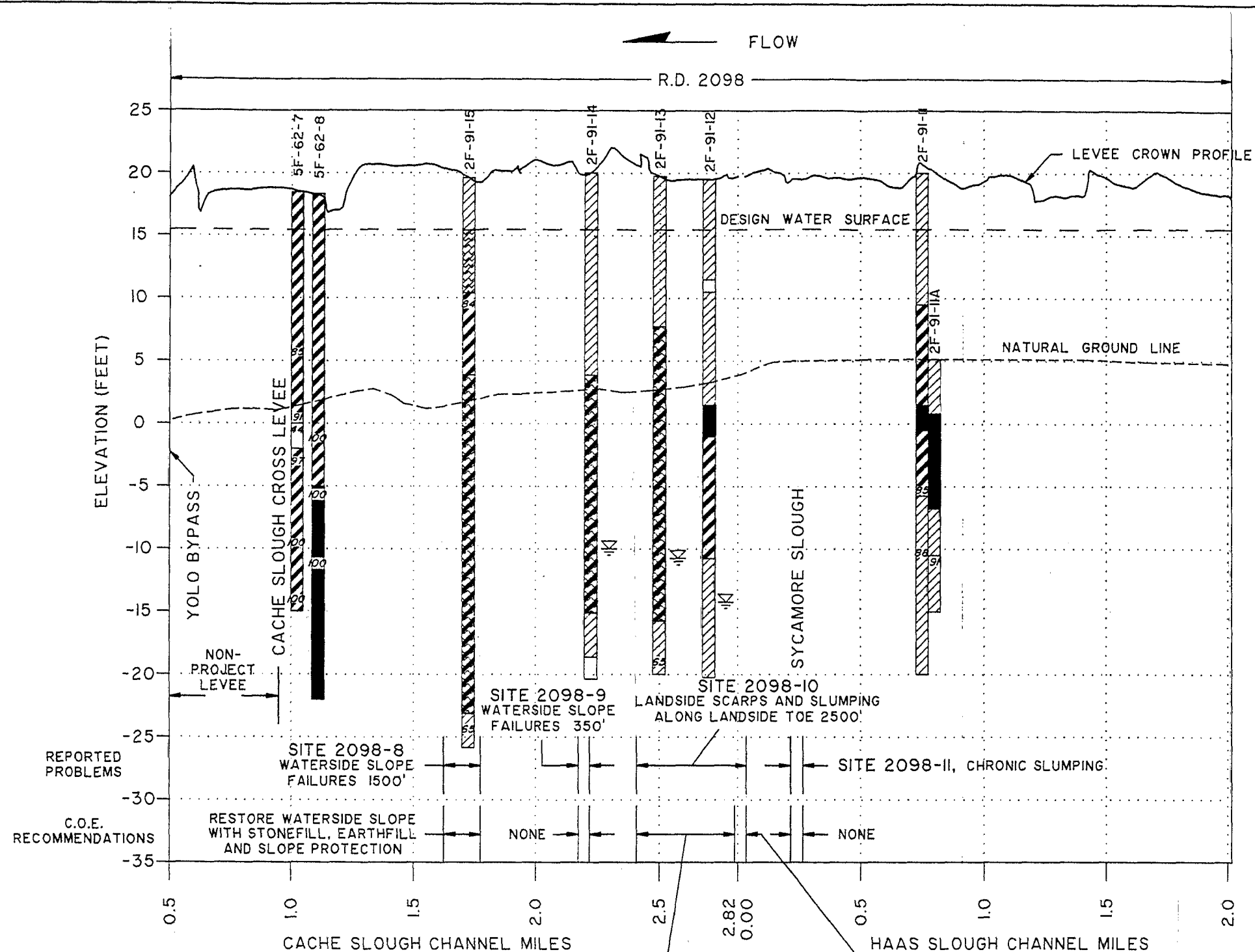
**LEVEE PROFILES  
CACHE SLOUGH  
LEFT BANK LEVEE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS  
DRAWN BY: R. IWASA

FEBRUARY 1993

**FIGURE 29**



**NOTES:**

1. REFER TO FIGURE 6 FOR NOTES.

SCALE: 1" = 0.5 MILES

SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION LOWER SACRAMENTO AREA, PHASE IV	
LEVEE PROFILES CACHE SLOUGH & HAAS SLOUGH LEFT BANK LEVEES	
SACRAMENTO DISTRICT, CORPS OF ENGINEERS	
PREPARED BY: D. RICKETTS	FEBRUARY 1993
DRAWN BY: R. IWASA	

FIGURE 30

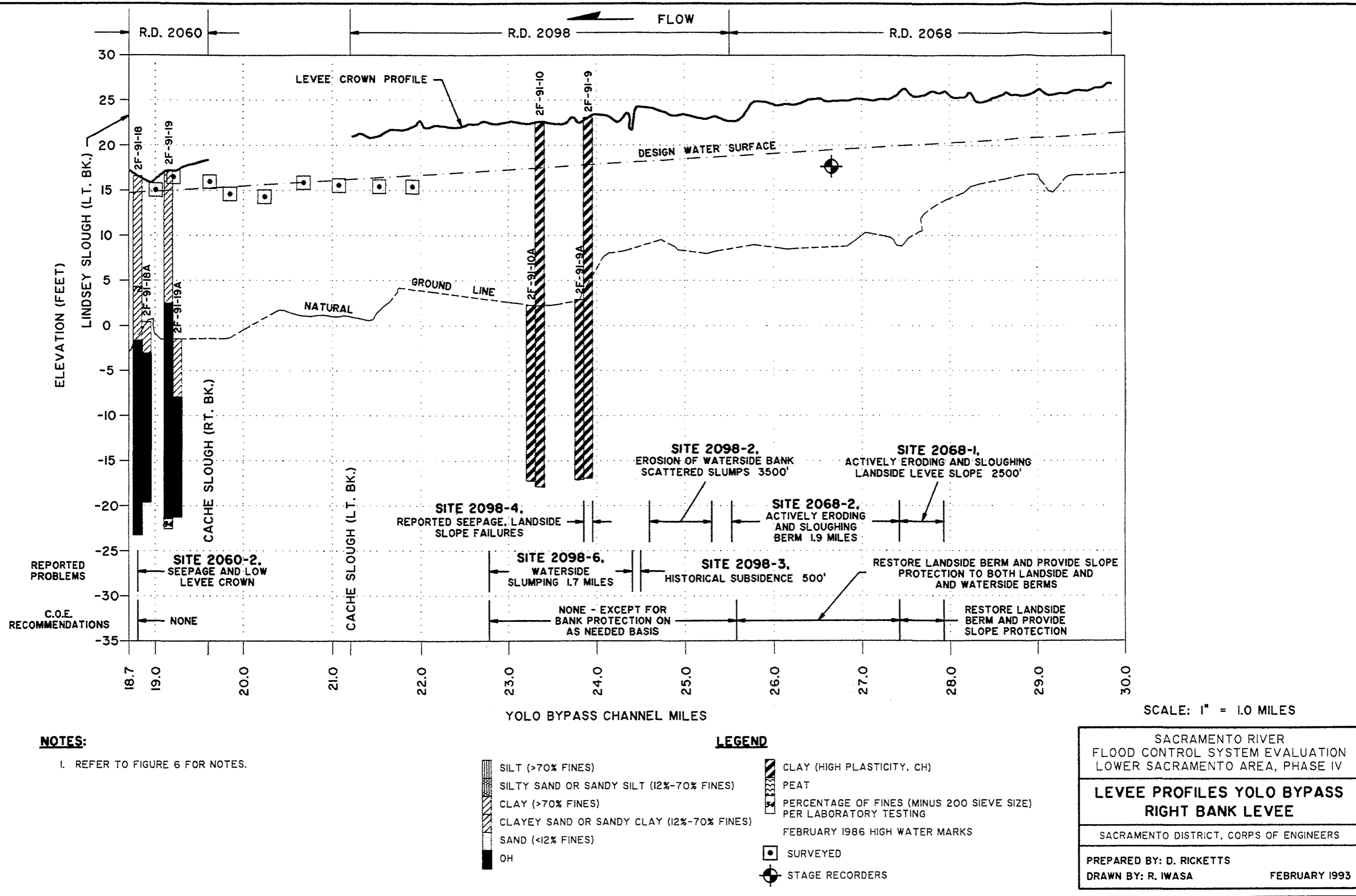
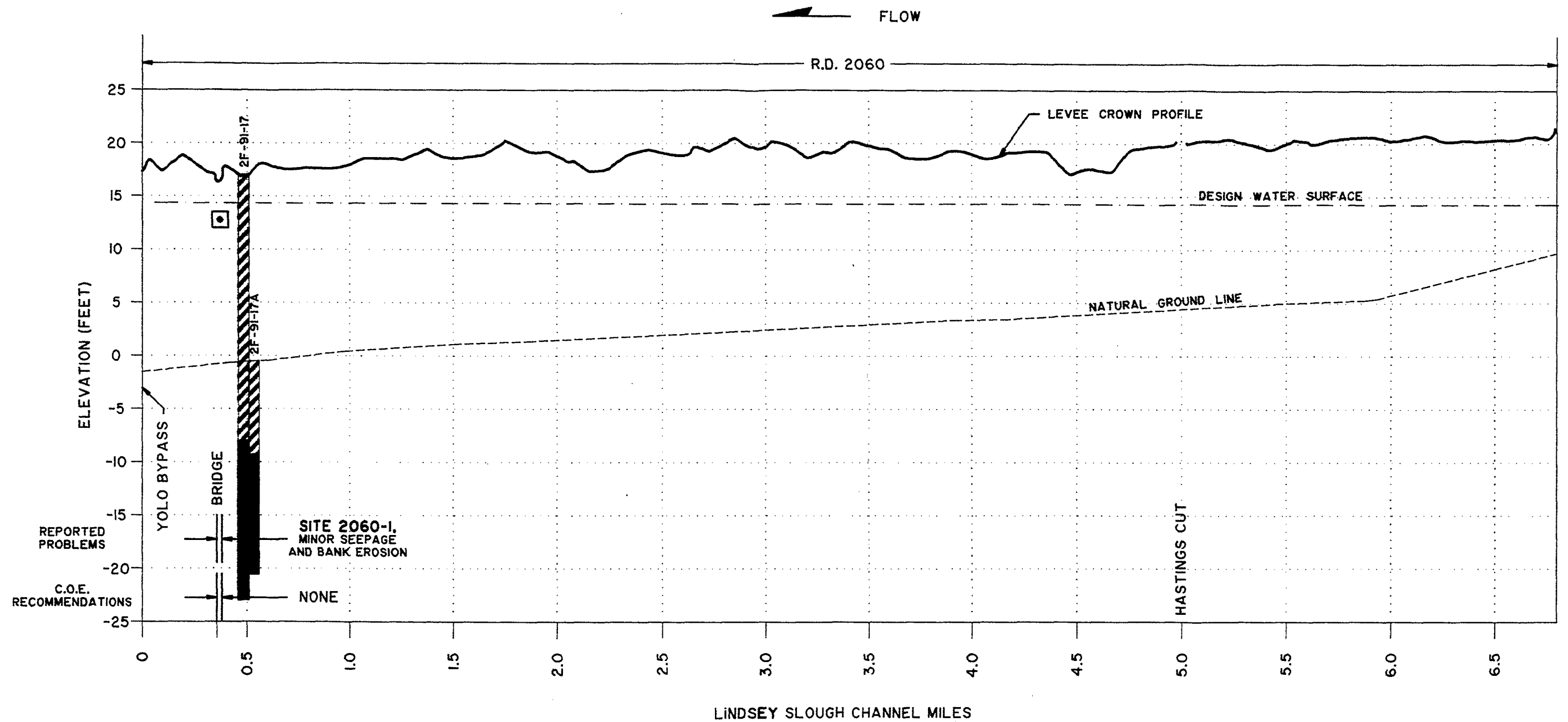


FIGURE 31



**NOTES:**

I. REFER TO FIGURE 6 FOR NOTES.

**LEGEND**

- |  |   |  |   |
|--|---|--|---|
|  | SILT (>70% FINES)                         |  | CLAY (HIGH PLASTICITY, CH)  |
|  | SILTY SAND OR SANDY SILT (12%-70% FINES)  |  | PEAT  |
|  | CLAY (>70% FINES)                         |  | PERCENTAGE OF FINES (MINUS 200 SIEVE SIZE) PER LABORATORY TESTING |
|  | CLAYEY SAND OR SANDY CLAY (12%-70% FINES) |  | FEBRUARY 1986 HIGH WATER MARKS                                    |
|  | SAND (<12% FINES)                         |  | SURVEYED  |
|  | OH  |  | STAGE RECORDERS   |

SCALE: 1" = 0.5 MILES

SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**LEVÉE PROFILES**  
**LINDSEY SLOUGH**  
**LEFT BANK LEVÉE**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

DRAWN BY: R. IWASA

FEBRUARY 1993

**FIGURE 32**



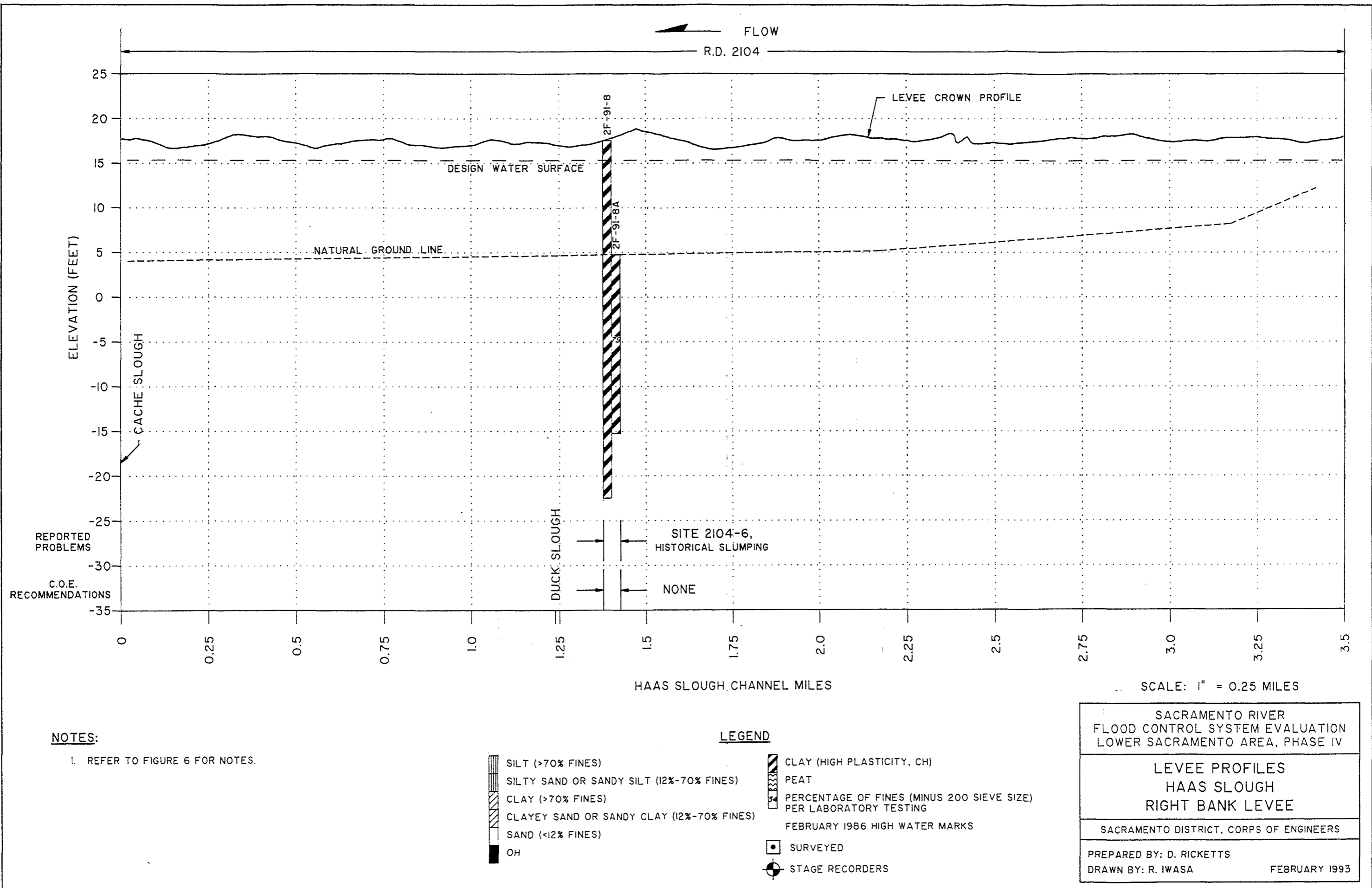
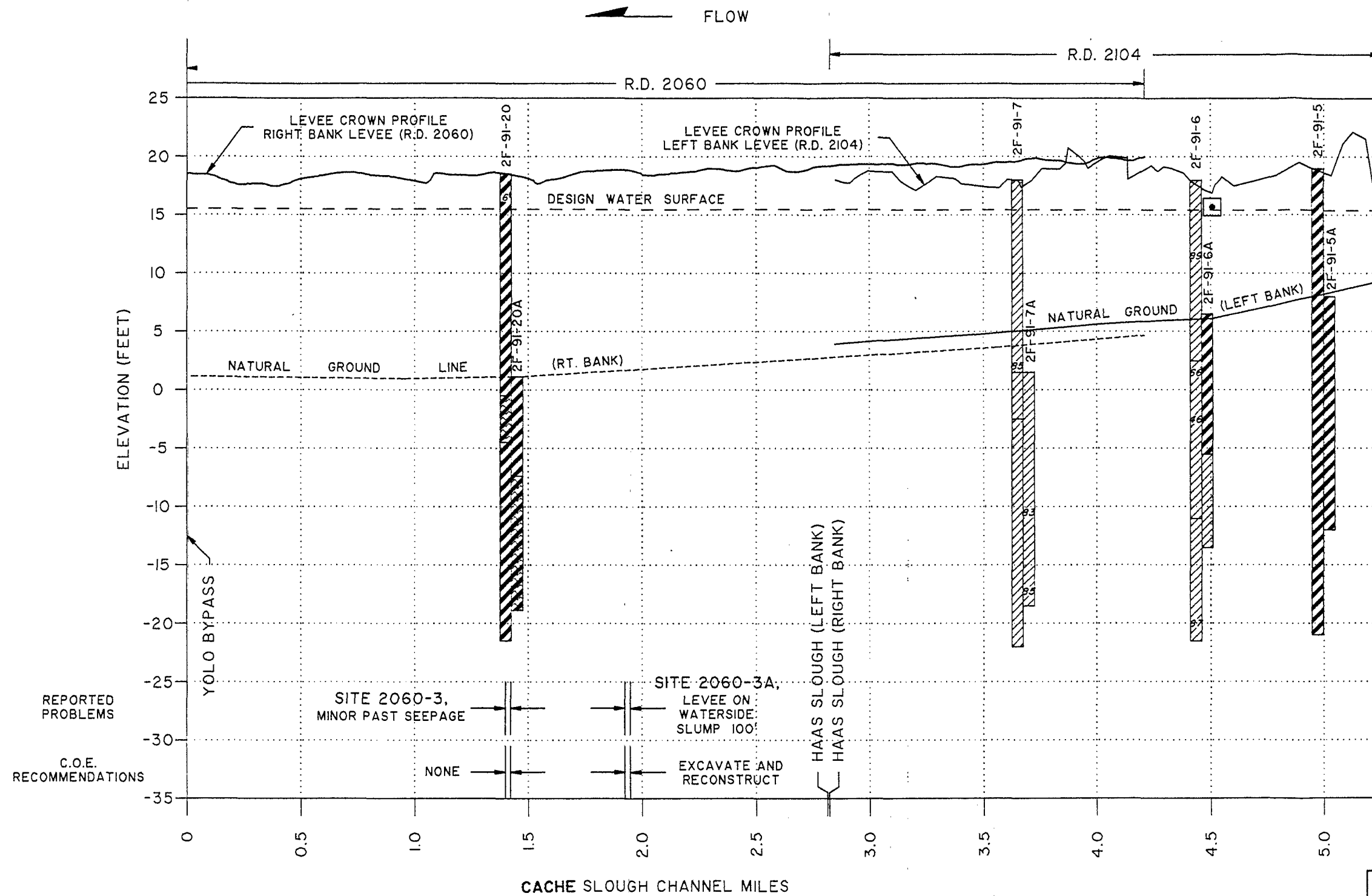


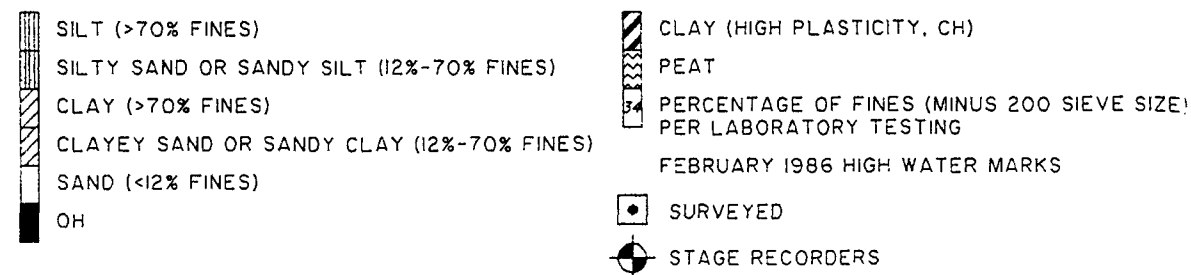
FIGURE 34



SCALE: 1" = 0.5 MILES

**NOTES:**

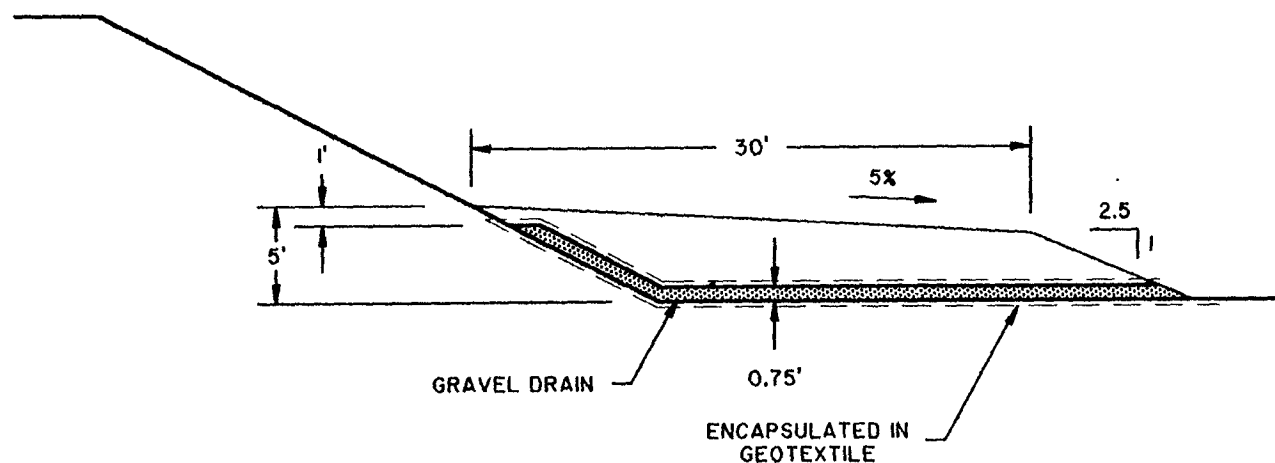
I. REFER TO FIGURE 6 FOR NOTES.



SACRAMENTO RIVER FLOOD CONTROL SYSTEM EVALUATION LOWER SACRAMENTO AREA, PHASE IV	
<b>LEVEE PROFILES</b> <b>CACHE SLOUGH</b> RIGHT BANK LEVEE (R.D. 2060) AND LEFT BANK LEVEE (R.D. 2104)	
SACRAMENTO DISTRICT, CORPS OF ENGINEERS	
PREPARED BY: D. RICKETTS DRAWN BY: R. IWASA	FEBRUARY 1993

FIGURE 35

**APPENDIX A**  
**RECONSTRUCTION ALTERNATIVES**



SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**ALTERNATIVE A**  
**SEEPAGE/STABILITY BERM (30')**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

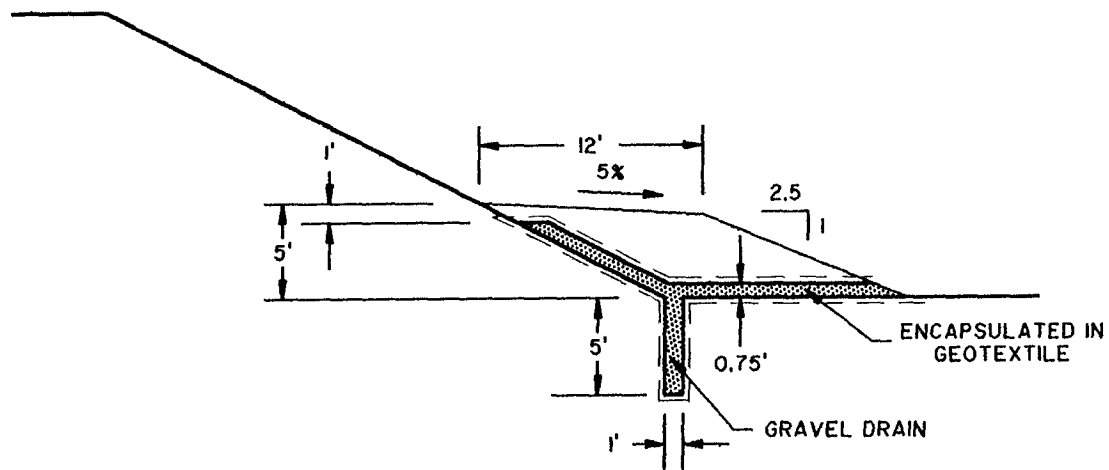
DRAWN BY: R. IWASA

FEBRUARY 1993

C-103604

FIGURE A-1

C-103604



SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**ALTERNATIVE B**  
**SEEPAGE/STABILITY BERM (12')**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

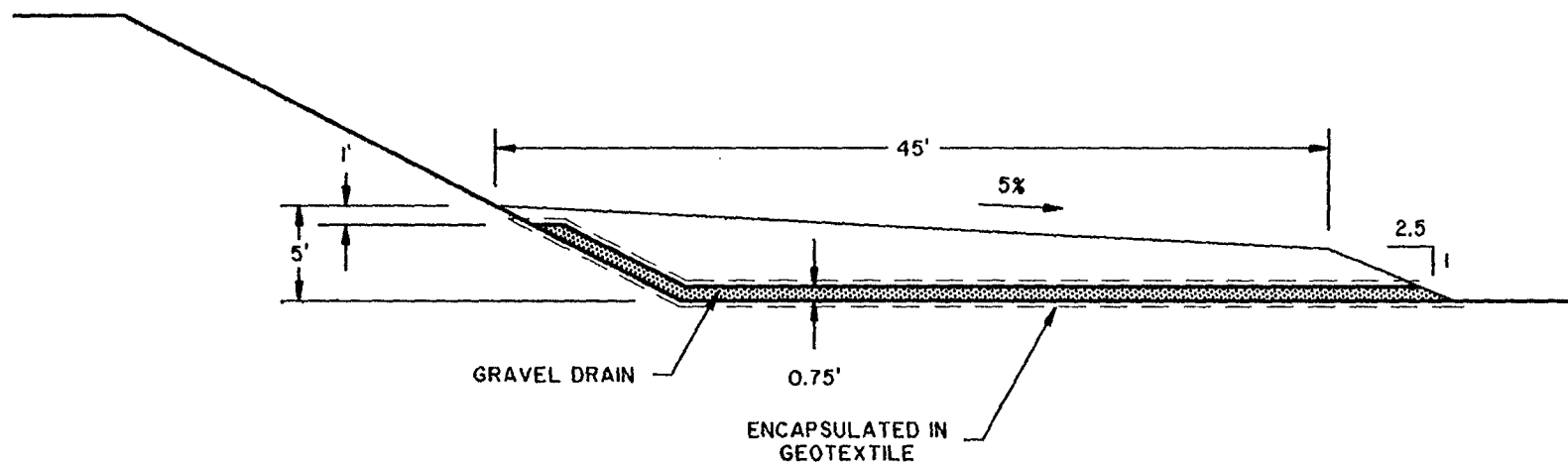
DRAWN BY: R. IWASA

FEBRUARY 1993

FIGURE A-2

C-103605

C-103605



SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**ALTERNATIVE C**  
**SEEPAGE/STABILITY BERM (45')**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

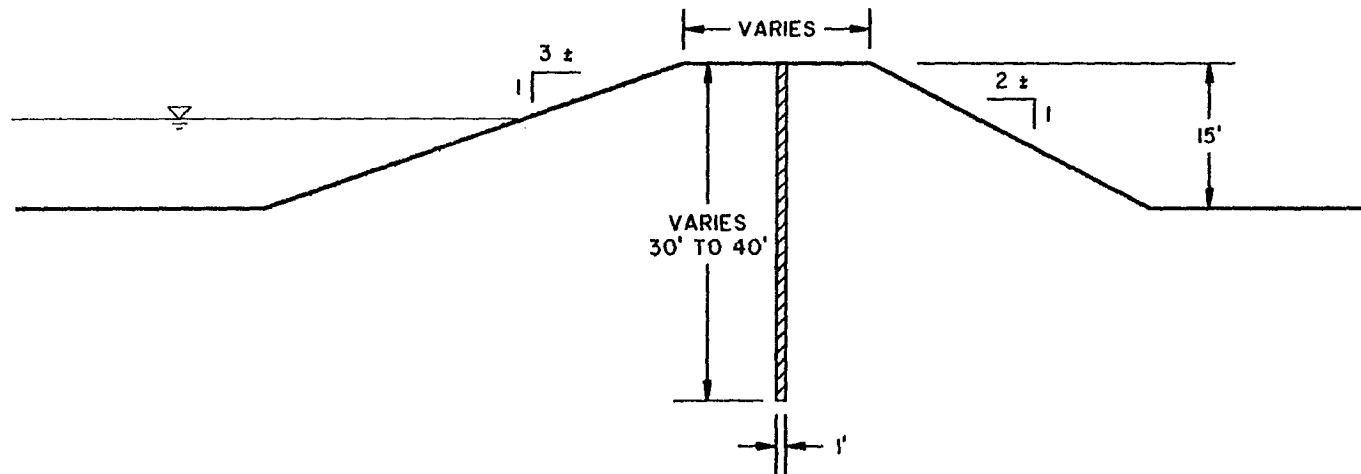
DRAWN BY: R. IWASA

FEBRUARY 1993

C-103606

FIGURE A-3

C-103606



SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**ALTERNATIVE D  
SLURRY CUTOFF WALL**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

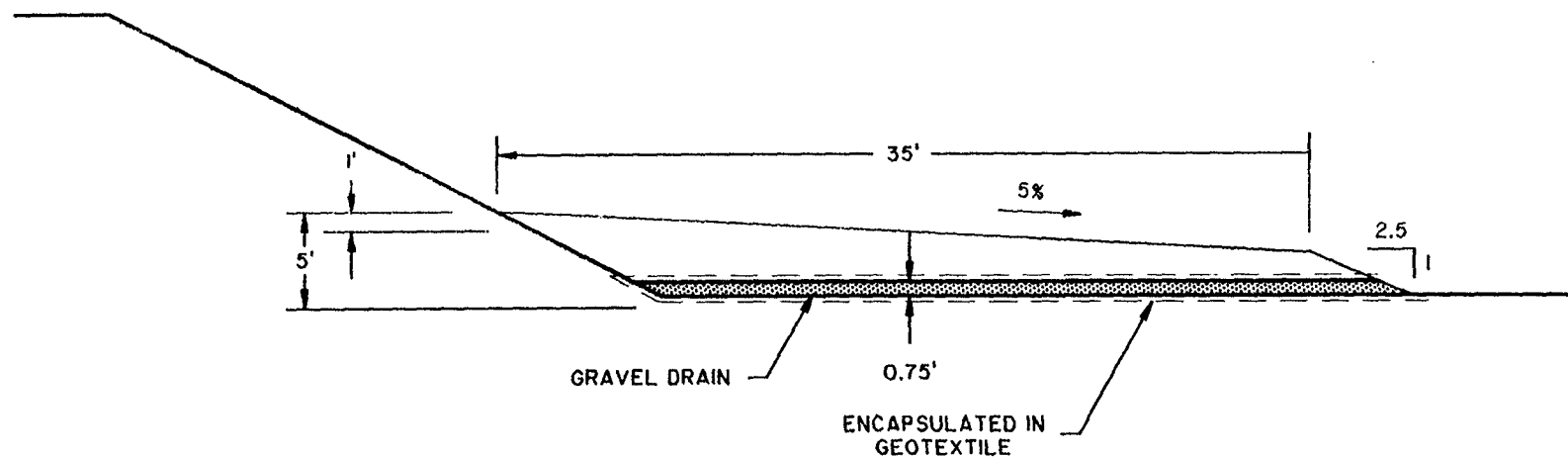
DRAWN BY: R. IWASA

FEBRUARY 1993

FIGURE A-4

C-103607

C-103607



SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**ALTERNATIVE E**  
**SEEPAGE BERM (35')**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

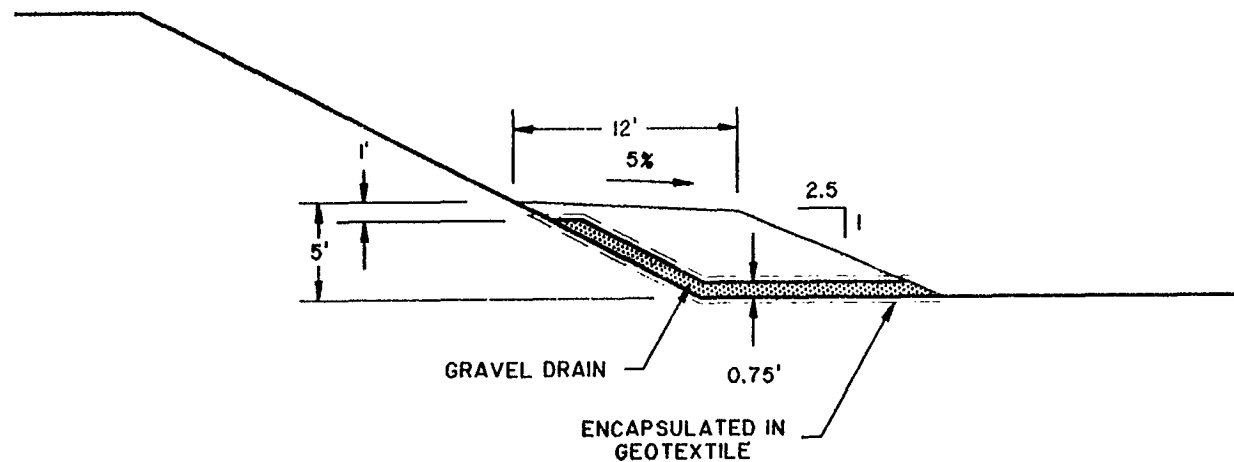
PREPARED BY: D. RICKETTS

DRAWN BY: R. IWASA

FEBRUARY 1993

C-103608

FIGURE A-5



SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**ALTERNATIVE F**  
**SITE BA-1**  
**STABILITY BERM (12')**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

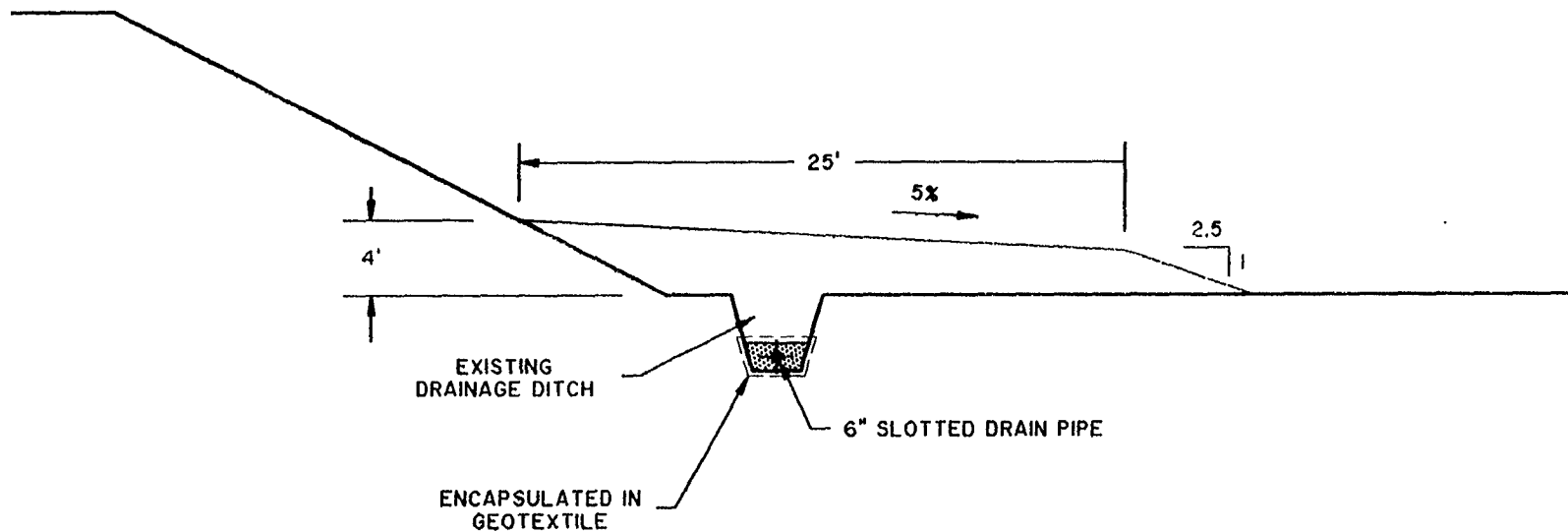
DRAWN BY: R. IWASA

FEBRUARY 1993

FIGURE A-6

C-103609

C-103609



SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

**ALTERNATIVE G**  
**SITE 349-I**  
**STABILITY BERM (25')**

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

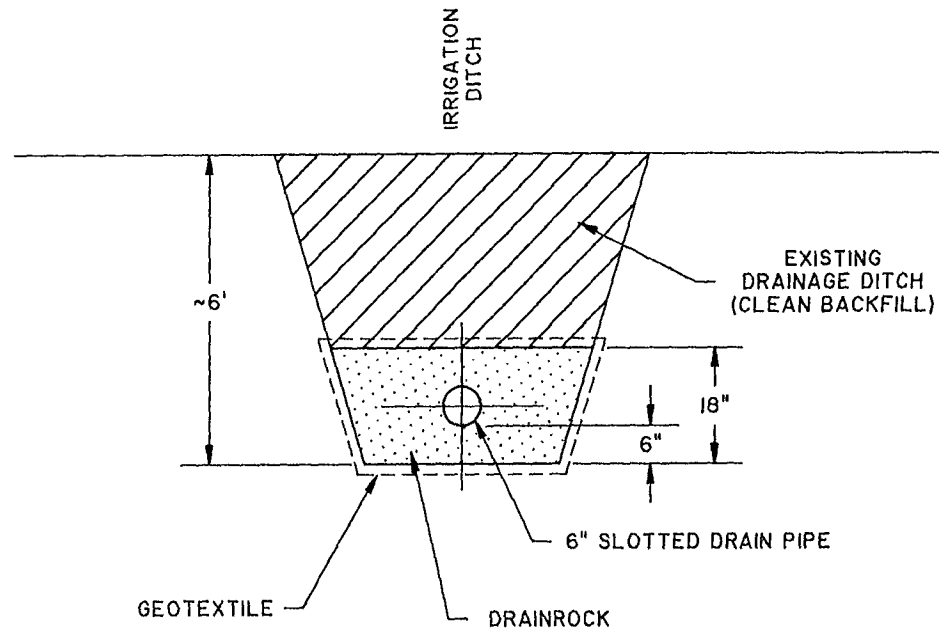
DRAWN BY: R. IWASA

FEBRUARY 1993

C-103610

FIGURE A-7

C-103610



SACRAMENTO RIVER  
FLOOD CONTROL SYSTEM EVALUATION  
LOWER SACRAMENTO AREA, PHASE IV

ALTERNATIVE H  
DRAINAGE COLLECTOR SYSTEM

SACRAMENTO DISTRICT, CORPS OF ENGINEERS

PREPARED BY: D. RICKETTS

DRAWN BY: R. IWASA

FEBRUARY 1993

C-103611

FIGURE A-8

**APPENDIX B**  
**SELECTED PHOTOGRAPHS**

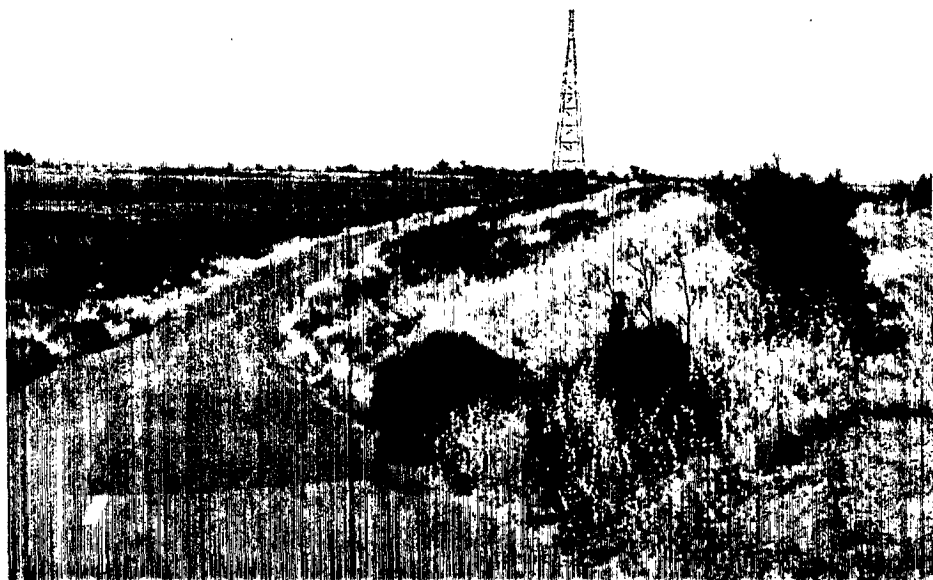


Photo 1 SITE 341-5 Looking downstream from where county road was moved off of levee crown in 1965. 5/22/92



Photo 2 SITE 341-1 Note seepage right center of photo. 5/22/92



Photo 3 SITE 341-4 Scour pond created by 1930s' levee break. 5/22/92



Photo 4 SITE 563-1 Seepage along levee landside toe. 5/22/92

C-103613

C-103613



Photo 5 SITE 563-2 Sloughing along landside slope. 5/22/92

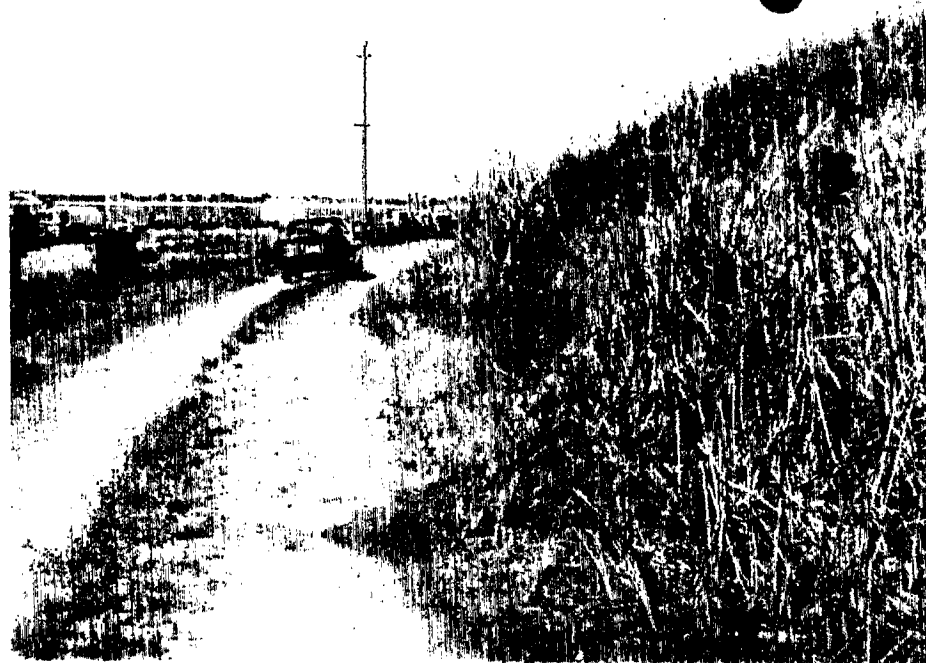


Photo 6 SITE 563-2 Seepage along levee landside toe. 5/22/92



Photo 7 SITE 563-4 Seepage reported in irrigation ditch. 5/22/92



Photo 8 SITE 556-2 Seepage along right bank levee in irrigation ditch. 5/22/92

C-103614

4 1 6 3 0 - C



Photo 9 SITE BA-1 Severe seepage along levee toe. 6/3/92

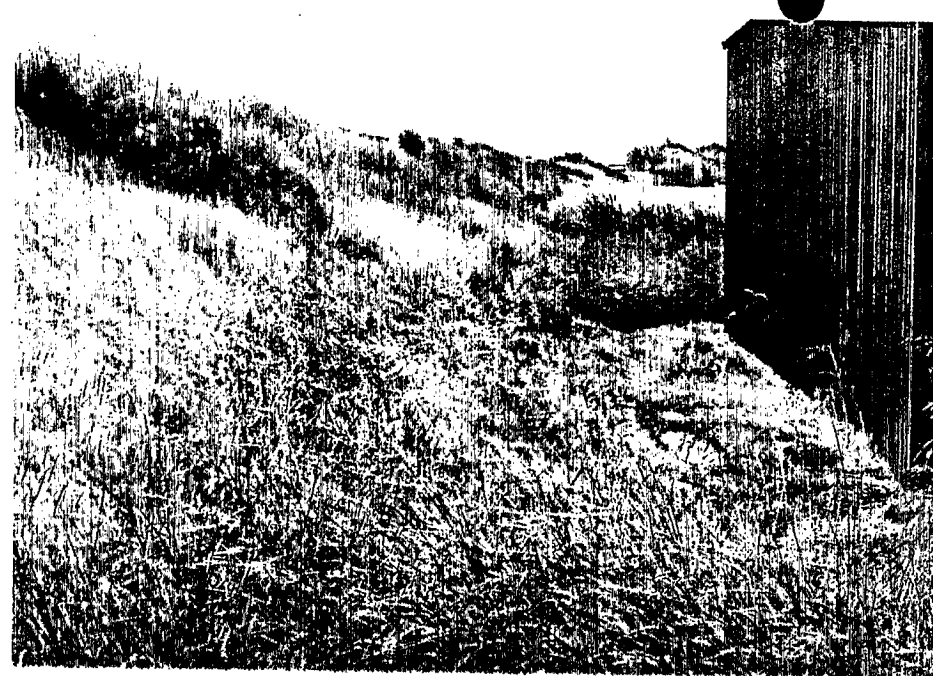


Photo 10 SITE BA-1 Seepage along levee toe. Note standing water. 6/3/92



Photo 11 SITE BA-2 Sacked sand boil at levee toe. 5/22/92



Photo 12 SITE 501-8 Seepage occurs along levee toe during high water. 12/16/92

C-103615

C-103615



Photo 13 SITE 349-1 Chronic seepage and sand boils in irrigation ditch.



Photo 14 SITE 349-1 Relief well installed in 1956, located along L/S toe, Sutter Slough. 12/16/92



Photo 15 SITE 349-1 Relief well along Sutter Slough L/S toe filled with sand. 12/16/92

C-103616

C-103616

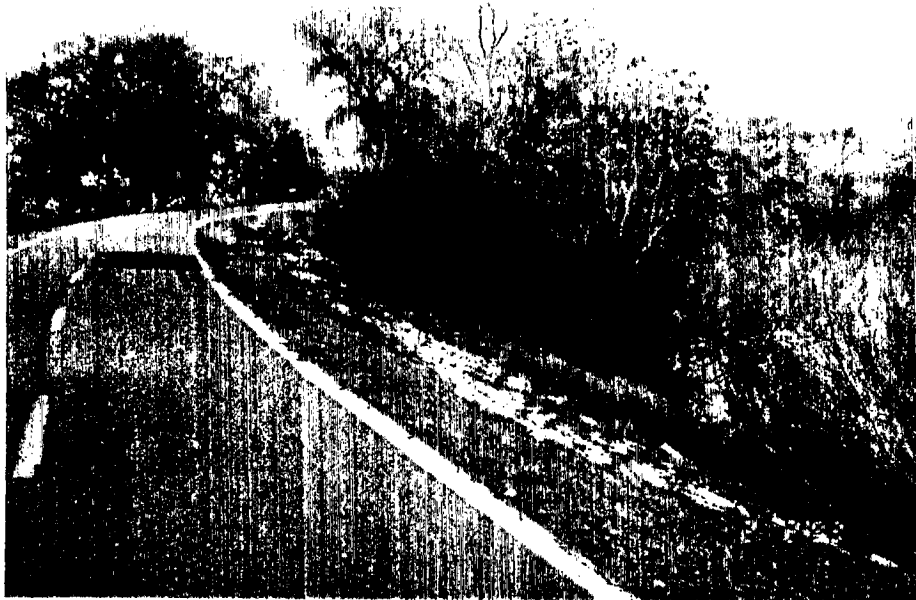


Photo 16 SITE 999-5 Progressive failure and erosion along waterside slope. 2/2/93



Photo 17 SITE 999-5 Closeup of cracks on lower slope with site 999-5. 2/2/93



Photo 18 SITE 501-3 Reported seepage in this area during high water stages. 2/16/92



Photo 19 SITE 501-5 Reported seepage area during high water stages. 12/16/92

C-103617

C-103617

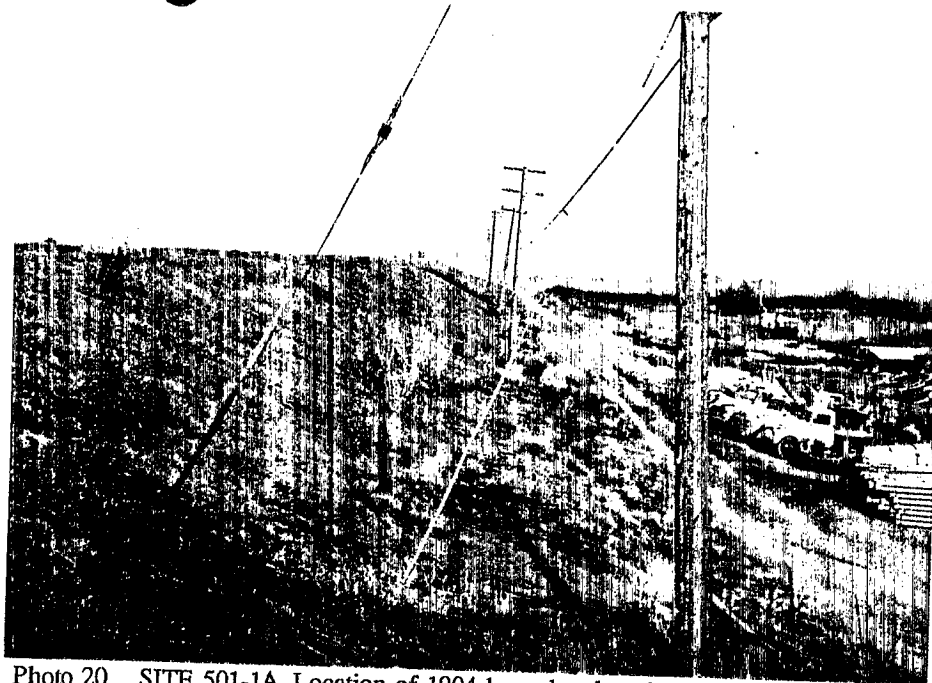


Photo 20 SITE 501-1A Location of 1904 levee break and sand boil on L/S slope in Feb. 1986 12/16/93



Photo 21 SITE 2098-8 Erosional scarps in waterside bank. 1/5/93



Photo 22 SITE 2098-8 Erosional scarps same area as photo 21. 1/5/93



Photo 23 SITE 2098-10 Erosion and sloughing of L/S slope. 1/5/93

C-103618

C-103618



Photo 24 SITE 2098-10A Landside slope failures along 400-foot reach. Note stress cracks in levee slope. 1/5/93

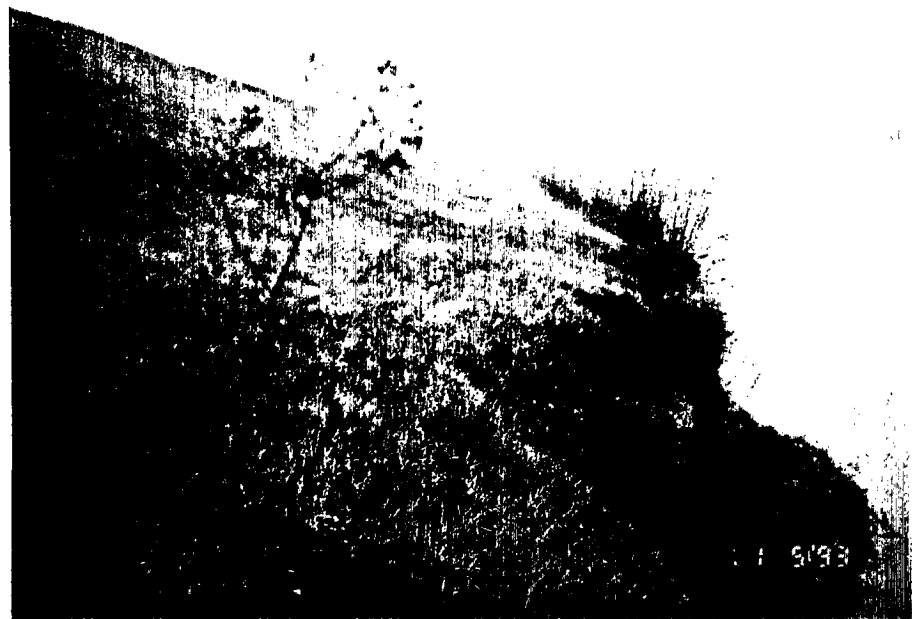


Photo 25 SITE 2068-1 Sloughing of lower levee slope, typical along this entire reach. 1/5/93



Photo 26 SITE 2068-1 Cracks in lower slope of levee. 1/5/93

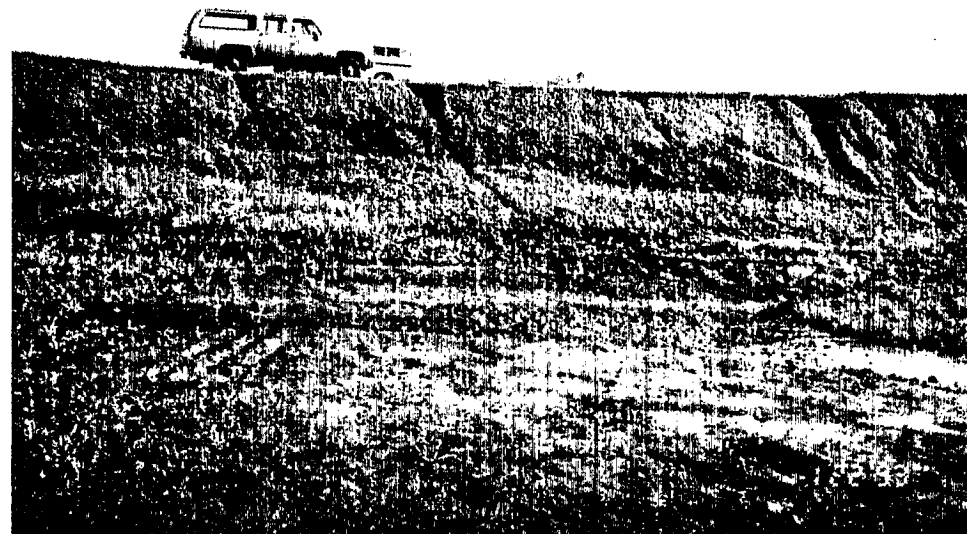


Photo 27 Erosional damage to levee slope from heavy January 1993 rainfall. 1/22/93



Photo 28 SITE 2060-1 Erosional scarp, 300 feet upstream of Hastings.  
Tract Bridge. 1/22/93.

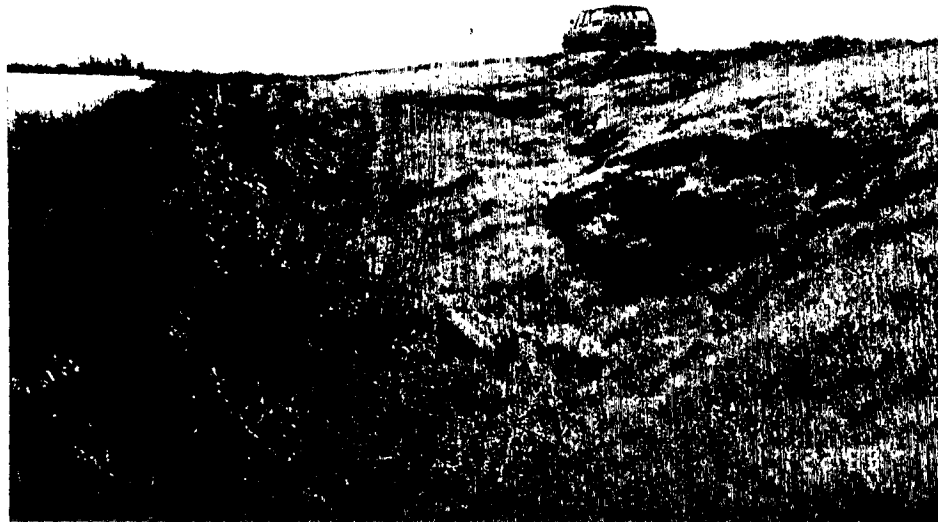


Photo 29 SITE 2060-3A Slope failure approximately 100 feet in length. 1/22/93



Photo 30 Erosional damage/bank sloughing 1000 feet upstream  
of confluence of Cache and Hass Sloughs 1/22/93

C-103620

C-103620